Verification Scheme for Unbonded Flexible Pipes

April 2022

Guidance Note
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BUREAU VERITAS MARINE & OFFSHORE

GENERAL CONDITIONS

1. INDEPENDENCE OF THE SOCIETY AND APPLICABLE TERMS

1.1 The Society shall remain at all times an independent contractor and neither the Society nor any of its officers, employees, servants, agents or subcontractors shall be or act as an employee, servant or agent of any other party hereto in the performance of the Services.

1.2 The operations of the Society in providing its Services are exclusively conducted by way of random inspections and do not, in any circumstances, involve monitoring or exhaustive verification.

1.3 The Society acts as a services provider. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty. The Society is not and may not be considered as an underwriter, broker in Unit's sale or chartering, expert in Unit's valuation, consulting engineer, controller, naval architect, designer, manufacturer, shipbuilder, repair or conversion yard, charterer or shipowner; none of the above listed being relieved from any of their expressed or implied obligations as a result of the interventions of the Society.

1.4 Only the Society is qualified to apply and interpret its Rules.

1.5 The Client acknowledges the latest versions of the Conditions and of the applicable Rules applying to the Services' performance.

1.6 Unless an express written agreement is made between the Parties on the applicable Rules, the applicable Rules shall be the Rules applicable at the time of entering into the relevant contract for the performance of the Services.

1.7 The Services' performance is solely based on the Conditions. No other terms shall apply whether express or implied.

2. DEFINITIONS

2.1 **"Certificate(s)"** means classification or statutory certificates, attestations and reports following the Society's intervention.

2.2 **"Certification"** means the activity of certification in application of national and international regulations or standards ("Applicable Referential"), in particular by delegation from different governments that can result in the issuance of a Certificate.

2.3 **"Classification"** means the classification of a Unit that can result or not in the issuance of a classification Certificate with reference to the Rules. Classification (or Certification as defined in clause 2.2) is an appraisement given by the Society to the Client, at a certain date, following surveys by its surveyors on the level of compliance of the Unit to the Society's Rules and/or to Applicable Referential for the Services provided. They cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.

2.4 **"Client"** means the Party and/or its representative requesting the Services.

2.5 **"Conditions"** means the terms and conditions set out in the present document.

2.6 **"Industry Practice"** means international maritime and/or offshore industry practices.

2.7 **"Intellectual Property"** means all patents, rights to inventions, utility models, copyright and related rights, trade marks, logos, service marks, trade dress, business and domain names, rights in trade dress or get-up, rights in goodwill or to sue for passing off, unfair competition rights, rights in designs, rights in computer software, database rights, topography rights, moral rights, rights in confidential information (including know-how and trade secrets), methods and protocols for Services, and any other intellectual property rights, in each case whether capable of registration, registered or unregistered and including all applications for and renewals, reversions or extensions of such rights, and all similar or equivalent rights or forms of protection in any part of the world.

2.8 **"Parties"** means the Society and Client together.

2.9 **"Party"** means the Society or the Client.

2.10 **"Register"** means the public electronic register of ships updated regularly by the Society.

2.11 **"Rules"** means the Society's classification rules (available online on veristar.com), guidance notes and other documents. The Society's Rules take into account at the date of their preparation the state of currently available and proven technical minimum requirements but are not a standard or a code of construction neither a guide for maintenance, a safety handbook or a guide of professional practices, all of which are assumed to be known in detail and carefully followed at all times by the Client.

2.12 **"Services"** means the services set out in clauses 2.2 and 2.3 but also other services related to Classification and Certification such as, but not limited to: ship and company safety management certification, ship and port security certification, maritime labour certification, training activities, all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board. The Services are carried out by the Society according to the Rules and/or the Applicable Referential and to the Bureau Veritas' Code of Ethics. The Society shall perform the Services according to the applicable national and international standards and Industry Practice and always on the assumption that the Client is aware of such standards and Industry Practice.

2.13 **"Society"** means the classification society **'Bureau Veritas Marine & Offshore SAS'**, a company organized and existing under the laws of France, registered in Nanterre under number 821 131 844, or any other legal entity of Bureau Veritas Group as may be specified in the relevant contract, and whose main activities are Classification and Certification of ships or offshore units.

2.14 **"Unit"** means any ship or vessel or offshore unit or structure of any type or part of it or system whether linked to shore, river bed or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as well head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

3. SCOPE AND PERFORMANCE

3.1 Subject to the Services requested and always by reference to the Rules, and/or to the Applicable Referential, the Society shall:

- review the construction arrangements of the Unit as shown on the documents provided by the Client;
- conduct the Unit surveys at the place of the Unit construction;
- class the Unit and enter the Unit's class in the Society's Register;
- survey the Unit periodically in service to note whether the requirements for the maintenance of class are met.

The Client shall inform the Society without delay of any circumstances which may cause any changes on the conducted surveys or Services.

3.2 The Society will not:

- declare the acceptance or commissioning of a Unit, nor its construction in conformity with its design, such activities remaining under the exclusive responsibility of the Unit's owner or builder;
- engage in any work relating to the design, construction, production or repair checks, neither in the operation of the Unit or the Unit's trade, neither in any advisory services, and cannot be held liable on those accounts.

4. RESERVATION CLAUSE

4.1 The Client shall always: (i) maintain the Unit in good condition after surveys; (ii) present the Unit for surveys; and (iii) inform the Society in due time of any circumstances that may affect the given appraisement of the Unit or cause to modify the scope of the Services.

4.2 Certificates are only valid if issued by the Society.

4.3 The Society has entire control over the Certificates issued and may at any time withdraw a Certificate at its entire discretion including, but not limited to, in the following situations: where the Client fails to comply in due time with instructions of the Society or where the Client fails to pay in accordance with clause 6.2 hereunder.

4.4 The Society may at times and at its sole discretion give an opinion on a design or any technical element that would 'in principle' be acceptable to the Society. This opinion shall not presume on the final issuance of any Certificate nor on its content in the event of the actual issuance of a Certificate. This opinion shall only be an appraisement made by the Society which shall not be held liable for it.

5. ACCESS AND SAFETY

5.1 The Client shall give to the Society all access and information necessary for the efficient performance of the requested Services. The Client shall be the sole responsible for the conditions of presentation of the Unit for tests, trials and surveys and the conditions under which tests and trials are carried out. Any information, drawing, etc. required for the performance of the Services must be made available in due time.

5.2 The Client shall notify the Society of any relevant safety issue and shall take all necessary safety-related measures to ensure a safe work environment for the Society or any of its officers, employees, servants, agents or subcontractors and shall comply with all applicable safety regulations.

6. PAYMENT OF INVOICES

6.1 The provision of the Services by the Society, whether complete or not, involves, for the part carried out, the payment of fees thirty (30) days upon issuance of the invoice.

6.2 Without prejudice to any other rights hereunder, in case of Client's payment default, the Society shall be entitled to charge, in addition to the amount not properly paid, interest equal to twelve (12) months LIBOR plus two (2) per-cent as of due date calculated on the number of days such payment is delinquent. The Society shall also have the right to withhold Certificates and other documents and/or to suspend or revoke the validity of Certificates.

6.3 In case of dispute on the invoice amount, the undisputed portion of the invoice shall be paid and an explanation on the dispute shall accompany payment so that action can be taken to resolve the dispute.

7. LIABILITY

7.1 The Society bears no liability for consequential loss. For the purpose of this clause consequential loss shall include, without limitation:

- Indirect or consequential loss;
- Any loss and/or deferral of production, loss of product, loss of use, loss of bargain, loss of revenue, loss of profit or anticipated profit, loss of business and business interruption, in each case whether direct or indirect.

The Client shall defend, release, save, indemnify, defend and hold harmless the Society from the Client's own consequential loss regardless of cause.

7.2 Except in case of wilful misconduct of the Society, death or bodily injury caused by the Society's negligence and any other liability that could not be, by law, limited, the Society's maximum liability towards the Client is limited to one hundred and fifty per-cent (150%) of the price paid by the Client to the Society for the Services having caused the damage. This limit applies to any liability of whatsoever nature and howsoever arising, including fault by the Society, breach of contract, breach of warranty, tort, strict liability, breach of statute.

7.3 All claims shall be presented to the Society in writing within three (3) months of the completion of Services' performance or (if later) the date when the events which are relied on were first discovered by the Client. Any claim not so presented as defined above shall be deemed waived and absolutely time barred.

8. INDEMNITY CLAUSE

8.1 The Client shall defend, release, save, indemnify and hold harmless the Society from and against any and all claims, demands, lawsuits or actions for damages, including legal fees, for harm or loss to persons and/or property tangible, intangible or otherwise which may be brought against the Society, incidental to, arising out of or in connection with the performance of the Services (including for damages arising out of or in connection with opinions delivered according to clause 4.4 above) except for those claims caused solely and completely by the gross negligence of the Society, its officers, employees, servants, agents or subcontractors.

9. TERMINATION

9.1 The Parties shall have the right to terminate the Services (and the relevant contract) for convenience after giving the other Party thirty (30) days' written notice, and without prejudice to clause 6 above.

9.2 The Services shall be automatically and immediately terminated in the event the Client can no longer establish any form of interest in the Unit (e.g. sale, scrapping).

9.3 The Classification granted to the concerned Unit and the previously issued Certificates shall remain valid until the date of effect of the termination notice issued, or immediately in the event of termination under clause 9.2, subject to compliance with clause 4.1 and 6 above.

9.4 In the event where, in the reasonable opinion of the Society, the Client is in breach, or is suspected to be in breach of clause 16 of the Conditions, the Society shall have the right to terminate the Services (and the relevant contracts associated) with immediate effect.

10. FORCE MAJEURE

10.1 Neither Party shall be responsible or liable for any failure to fulfil any term or provision of the Conditions if and to the extent that fulfilment has been delayed or temporarily prevented by a force majeure occurrence without the fault or negligence of the Party affected and which, by the exercise of reasonable diligence, the said Party is unable to provide against.

10.2 For the purpose of this clause, force majeure shall mean any circumstance not being within a Party's reasonable control including, but not limited to: acts of God, natural disasters, epidemics or pandemics, wars, terrorist attacks, riots, sabotages, impositions of sanctions, embargoes, nuclear, chemical or biological contaminations, laws or action taken by a government or public authority, quotas or prohibition, expropriations, destructions of the worksite, explosions, fires, accidents, any labour or trade disputes, strikes or lockouts.

11. CONFIDENTIALITY

11.1 The documents and data provided to or prepared by the Society in performing the Services, and the information made available to the Society, will be treated as confidential except where the information:

- is properly and lawfully in the possession of the Society;
- is already in possession of the public or has entered the public domain, other than through a breach of this obligation;
- is acquired or received independently from a third party that has the right to disseminate such information;
- is required to be disclosed under applicable law or by a governmental order, decree, regulation or rule or by a stock exchange authority (provided that the receiving Party shall make all reasonable efforts to give prompt written notice to the disclosing Party prior to such disclosure).

11.2 The Parties shall use the confidential information exclusively within the framework of their activity underlying these Conditions.

11.3 Confidential information shall only be provided to third parties with the prior written consent of the other Party. However, such prior consent shall not be required when the Society provides the confidential information to a subsidiary.

11.4 Without prejudice to sub-clause 11.1, the Society shall have the right to disclose the confidential information if required to do so under regulations of the International Association of Classifications Societies (IACS) or any statutory obligations.

12. INTELLECTUAL PROPERTY

12.1 Each Party exclusively owns all rights to its Intellectual Property created before or after the commencement date of the Conditions and whether or not associated with any contract between the Parties.

12.2 The Intellectual Property developed by the Society for the performance of the Services including, but not limited to drawings, calculations, and reports shall remain the exclusive property of the Society.

13. ASSIGNMENT

13.1 The contract resulting from to these Conditions cannot be assigned or transferred by any means by a Party to any third party without the prior written consent of the other Party.

13.2 The Society shall however have the right to assign or transfer by any means the said contract to a subsidiary of the Bureau Veritas Group.

14. SEVERABILITY

14.1 Invalidity of one or more provisions does not affect the remaining provisions.

14.2 Definitions herein take precedence over other definitions which may appear in other documents issued by the Society.

14.3 In case of doubt as to the interpretation of the Conditions, the English text shall prevail.

15. GOVERNING LAW AND DISPUTE RESOLUTION

15.1 These Conditions shall be construed in accordance with and governed by the laws of England and Wales.

15.2 Any dispute shall be finally settled under the Rules of Arbitration of the Maritime Arbitration Chamber of Paris ("CAMP"), which rules are deemed to be incorporated by reference into this clause. The number of arbitrators shall be three (3). The place of arbitration shall be Paris (France). The Parties agree to keep the arbitration proceedings confidential.

15.3 Notwithstanding clause 15.2, disputes relating to the payment of the Society's invoices may be submitted by the Society to the *Tribunal de Commerce de Nanterre*, France, or to any other competent local Court, at the Society's entire discretion.

16. PROFESSIONAL ETHICS

16.1 Each Party shall conduct all activities in compliance with all laws, statutes, rules, economic and trade sanctions (including but not limited to US sanctions and EU sanctions) and regulations applicable to such Party including but not limited to: child labour, forced labour, collective bargaining, discrimination, abuse, working hours and minimum wages, anti-bribery, anti-corruption, copyright and trademark protection, personal data protection (https://personaldataprotection.bureauveritas.com/privacypolicy).

Each of the Parties warrants that neither it, nor its affiliates, has made or will make, with respect to the matters provided for hereunder, any offer, payment, gift or authorization of the payment of any money directly or indirectly, to or for the use or benefit of any official or employee of the government, political party, official, or candidate.

16.2 In addition, the Client shall act consistently with the Bureau Veritas' Code of Ethics and, when applicable, Business Partner Code of Conduct both available at https://group.bureauveritas.com/group/corporate-social-responsibility/operational-excellence.

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SECTION 1 GENERAL

1 Scope

1.1 Purpose

1.1.1 The present Guidance Note describes the Bureau Veritas (hereafter referred as “the Society”) verification scheme for unbonded Flexible Pipes and associated ancillary items under the scope of API17J standard (see [5.1]).

1.2 Application

1.2.1 This Guidance Note covers the certification scheme related to unbonded Flexible Pipes with their end-fittings designed and manufactured as per API 17J Specification.

1.2.2 This Guidance Note does not apply to the following products:

- unbonded flexible pipes for use for choke and kill applications (API 16C)
- bonded flexible pipes (API 17K) and
- umbilicals (API 17E).

However, the principles set forth in the present Guidance Note may be followed for the assessment of these products.

1.2.3 This Guidance Note being focused on the description of the verification scheme, it does not provide any design criterion or requirement on the unbonded Flexible Pipes as such. The applicable requirements are given in API 17J Specification, possibly supplemented by end-users requirements.

2 Definitions

2.1

2.1.1 The following terminology is used in the present document, in accordance with API 17J and API 17Q.

2.1.2 Certificate Of Conformity (COC)

Document established by an IVA within the context of a commercial project, certifying that a flexible pipe line and end-fittings has been manufactured and designed in accordance with API 17J requirements as well as purchaser requirements.

2.1.3 Component

Collection of sub-components which when brought together function as a unit (e.g. connector, gate valve, pressure transducers).

2.1.4 Design Methodology Verification Report

Evaluation report prepared by an independent verification agent (IVA) at the time of an initial review, for a specific Manufacturer, confirming the suitability and appropriate limits on the Manufacturer's design methodologies, manufacturing processes, and materials. This report may include occasional amendments or revisions to address extensions beyond previous limits or revisions of methodologies.

2.1.5 Environment

Internal, external and operational conditions to which an equipment is exposed, including physical, chemical, biological and usage conditions (i.e. seawater environment, water depth, seabed conditions, reservoir conditions, pressure, temperature, etc.).

2.1.6 Failure mode

Effect by which a failure is observed on the failed item (i.e. the loss of a required functionality, e.g. loss of containment).

2.1.7 Flexible riser

A flexible pipe connecting a platform/buoy/ship to a flowline, seafloor installation, or another platform where the riser may be freely suspended, restrained to some extent (buoys, chains), totally restrained, or enclosed in a tube (I- or J-tubes).

2.1.8 Independent Design Review Certificate (IRC)

Document established by an IVA within the context of a commercial project, certifying that the flexible pipe design meets API 17J requirements as well as purchaser requirements.

2.1.9 Independent Verification Agent (IVA)

Independent party or group, selected by the Manufacturer, who is responsible for the review and certification of the indicated product concept (e.g. pipe and end fitting concept) and flexible pipe associated design, manufacturing methodologies and criteria, material qualification and prototype performance based on the technical literature, analyses, results, and other information provided by the Manufacturer to establish the range of applicability. An agent may also be called upon to witness some measurements and tests related to material qualification, manufacturing process control, validation of design methodologies, and prototype tests. By extension, the IVA also refers to an Independent party involved in any non-generic certification activities related to unbonded flexible pipes (e.g. project certification against AP 17J requirements, commercial lines manufacturing certification, assessment of operating management plan).

2.1.10 Limit state

State beyond which an item no longer satisfies the requirements. The following categories of limit states are of relevance for structures design:

ULS : Ultimate Limit State

FLS : Fatigue Limit State

ALS : Accidental Limit State

SLS : Serviceability Limit State.

2.1.11 Manufacturer

Flexible Pipe manufacturer.

2.1.12 Prototype

Trial product produced to test a concept or process.

2.1.13 Prototype test

Test to establish or verify a principal performance characteristic for a particular pipe design, which may be a new or established design, and to also validate Manufacturer design methodology and so provide a basis for the IVA verification.

2.1.14 Qualification

Process of confirming, by examination and provision of evidence, that equipment meets specified requirements for the intended use; the combination of Verification and Validation activities.

2.1.15 Q-FMECA (Qualification Failure Mode Effects and Criticality Analysis)

Integrated FMECA (Qualification Failure Mode Effects and Criticality Analysis) with the purpose of identifying and prioritizing qualification activities for a technology.

2.1.16 Qualification testing

Testing by which the structural, functional, fabrication, and reliability performance of a pipe concept, its components, or materials used may be evaluated in order to demonstrate suitability for the specified service life in a specific application. Qualification testing can also be used to validate the Manufacturer's design methodology for a new pipe design.

2.1.17 Quality

Conformance to specified requirements.

2.1.18 Quality assurance (QA)

Planned, systematic, and preventive actions that are required to ensure that materials, products, or services meet specified requirements.

2.1.19 Quality control (QC)

Inspection, test, or examination to ensure that materials, products, or services conform to specified requirements.

2.1.20 Range of applicability

It defines the range of use specified by users complemented by the characteristics of the qualified envelop / extent of evidence provided for qualification.

2.1.21 Range of use

Range of operating conditions for which the flexible pipe is specified by users (for example fluid composition, internal / external pressure and temperature, etc.).

2.1.22 Specification
Document in which function, performance, design and operating requirements are defined, together with associated reliability and integrity goals and requirements.

2.1.23 Standard Qualification Program (SQP)
Qualification program that utilizes qualification activities prescribed within existing standards applicable to the technology.

2.1.24 Sub-supplier
Raw material supplier to flexible pipe Manufacturer's supplier. For example sub-supplier produces the round wire used by steel wire supplier (at which plant the wire is drawn and rolled).

2.1.25 Supplier
Flexible pipe manufacturer's supplier.

2.1.26 System
Fluid conveyance system, connected to field equipment in both extremities, in operation or ready to operate, for which the flexible pipe is the primary component and includes ancillary components and accessories attached directly or indirectly to the pipe.

2.1.27 Technology
Component, a product, a physical process, or system used to perform specific functions and/or to achieve specific goals.

2.1.28 Technology Qualification Program (TQP)
Qualification program that utilizes a Q-FMECA to identify qualification activities necessary to qualify the technology in line with the identified goals and requirements.

2.1.29 Type Approval Certification (TAC)
Independent review and certification by an IVA of the indicated product concept (e.g. pipe and end fitting concept) and flexible pipe associated design, manufacturing methodologies and criteria, material qualification and prototype performance based on the technical literature, analyses, results, and other information provided by the Manufacturer to establish the range of applicability.

2.1.30 Type Approval Certification Report
Terminology for API 17J Design Methodology Verification Report.

2.1.31 Unbonded flexible pipe
A pipe construction that consists of separate unbonded polymeric and helical reinforcement layers, which allows relative movement between layers.

2.1.32 Uncertainty
State of having limited knowledge where it is impossible to exactly describe the existing state or future outcome(s).

2.1.33 Validation
Confirmation, by testing, that the requirements for a specific intended use or application have been fulfilled. The confirmation can comprise activities such as (list is not all-inclusive): Prototype testing, functional and/or operational testing of production products, testing specified by industry standards and/or regulatory requirements, field performance testing and reviews.

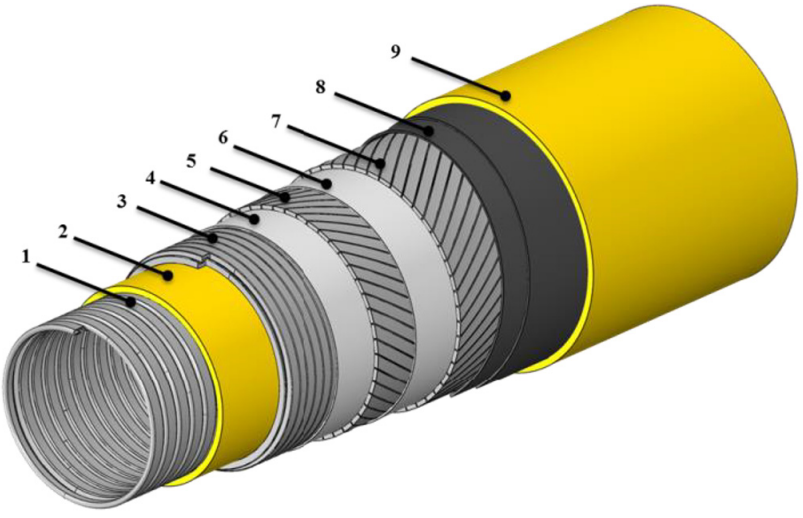
2.1.34 Verification
Confirmation, through provision of objective evidence, that specified requirements have been fulfilled. The confirmation can comprise activities such as (list is not all-inclusive): performing alternative calculations, comparing a new design specification with a similar proven design specification, undertaking investigative tests and demonstrations, reviewing design output documents against specified requirements.

3 Unbonded flexible pipe description

3.1 General

3.1.1 Unbonded Flexible pipes are complex products, consisting of an assembly of multiple metallic and polymeric layers, submitted to severe loadings in terms of service conditions, transported fluid characteristics and extreme and dynamic mechanical loadings.

Figure 1 : Illustration of standard arrangement of an API 17B Family III flexible pipe



The standard arrangement of an API 17B Family III flexible pipe, taken as example, as well as the basic function of each layer is recalled hereafter. Fig 1 presents the typical arrangement of such flexible pipe, composed of the following layers:

- Layer 1:

  A carcass, which is an interlocked metallic strip made of stainless steel and aimed at providing the radial strength of the pipe towards hydrostatic collapse and crushing loads.
- Layer 2:

  An internal pressure sheath manufactured from an extruded polymer material and aiming at providing the fluid containment.
- Layer 3:

  A pressure armour layer made of interlocked steel wires wound at a short pitch and aimed at providing the basic pressure capacity of the pipe.
- Layers 4 and 6:

  An anti-wear layer which is generally a tape and is aimed at preventing metal-to-metal contact.
- Layers 5 and 7:

  Tensile armour wires (one or two pairs of layers) made of steel rectangular wires and aimed at providing the resistance to axial loads.
- Layer 8:

  An antibuckling layer made of high strength composite materials wound to prevent the radial buckling of the tensile armours under axial compressive loads.
- Layer 9:

  An outer sheath manufactured from an extruded polymer material and aimed at maintaining the overall pipe assembly and protecting the components of the pipe annulus from the external environment, e.g. mechanical damage or corrosion.

Other layers may be added, such as an external protection sheath to protect the external layer from abrasion in contact with external structures or sea-bottom, insulation material tapes to provide improved thermal insulation, intermediate sheath to add a 2nd barrier versus external environment, additional pressure armour to increase internal pressure resistance capacity, etc.

4 Verification scheme for flexible pipes

4.1 Product verification specificities

4.1.1 Contrary to other segments of the oil and gas industry for which the verification activities can be performed during projects and solely based on recognized standards, the verification of flexible pipes can generally not be addressed properly using such approach, due to the following specificities:

- the geometries and materials of the metallic wires as well as the polymer layers are specific to each manufacturer and so is the general design philosophy of flexible pipes cross-sections and end-fittings

- the fabrication process and control methods are specific to each manufacturer within the limits defined by API 17J while the unbonded flexible pipes are by nature products for which the final performances are closely linked to the manufacturing
- the flexible pipes are not on-the-shelf products but are generally tailor made depending on the external conditions (e.g. static/dynamic, flow assurance requirements, transported fluid, water depth) and the function to be met (e.g. Production, Export, Injection)
- the flexible pipe industry is a competitive industry, implying that significant R&D work is carried out in order to improve competitiveness of the pipes and the suitability to harsher and harsher conditions, in terms of water depth, severity of transported fluids or dynamic loads. This entails a strong need for confidentiality of the quickly evolving technologies used
- the unbonded flexible pipe is a complex product in itself due to its composite multi-layer nature and its design requires addressing many fields of expertise. The trend for optimization tends to move more and more towards complex methodologies and couplings between phenomena that were addressed independently in the past with inherent conservatism
- the qualification and model validation by testing is frequently required due to the complexity of the tailor made flexible pipe products.

These specificities entail some consequences regarding the certification strategy and timeline for flexible pipes:

- the quickly evolving, confidential, manufacturer's specific designs cannot be addressed in details in common normative document. API 17J has set prescriptive requirements and criteria for some design and material aspects together with some goal setting stipulations in order to fit with these product specificities
- the complexity of the product and of its design methodologies, the variety of failure modes to be examined and the need to consider the whole qualification record makes it very difficult in practice to perform a satisfactory certification work within a project schedule
- the significant testing costs and potential number of tests to be performed to fully qualify and certify a flexible pipe from scratch will be prohibitive in a project context.

4.2 Qualification of new technology

4.2.1 As the flexible pipe industry is a competitive industry that keeps pushing the boundaries of the technology towards more and more challenging applications, it is a common practice for flexible pipes manufacturers to develop new technologies, either related to design methodologies, materials or manufacturing methods.

One advisable exercise, to decide on the required Qualification Programme aimed at demonstrating the suitability of a new technology is to carry out a Q-FMECA (Qualification Failure Mode Effects and Criticality Analysis). It will identify the risks and uncertainties potentially brought by the new technology and conclude on the contents of the Qualification Programme required to remove the uncertainties and make the risks manageable. A Q-FMECA will provide details regarding threats and weaknesses, which should be used to define testing or analysis activities in order to demonstrate the ability of the flexible pipe embodying the new technology to meet specified requirements.

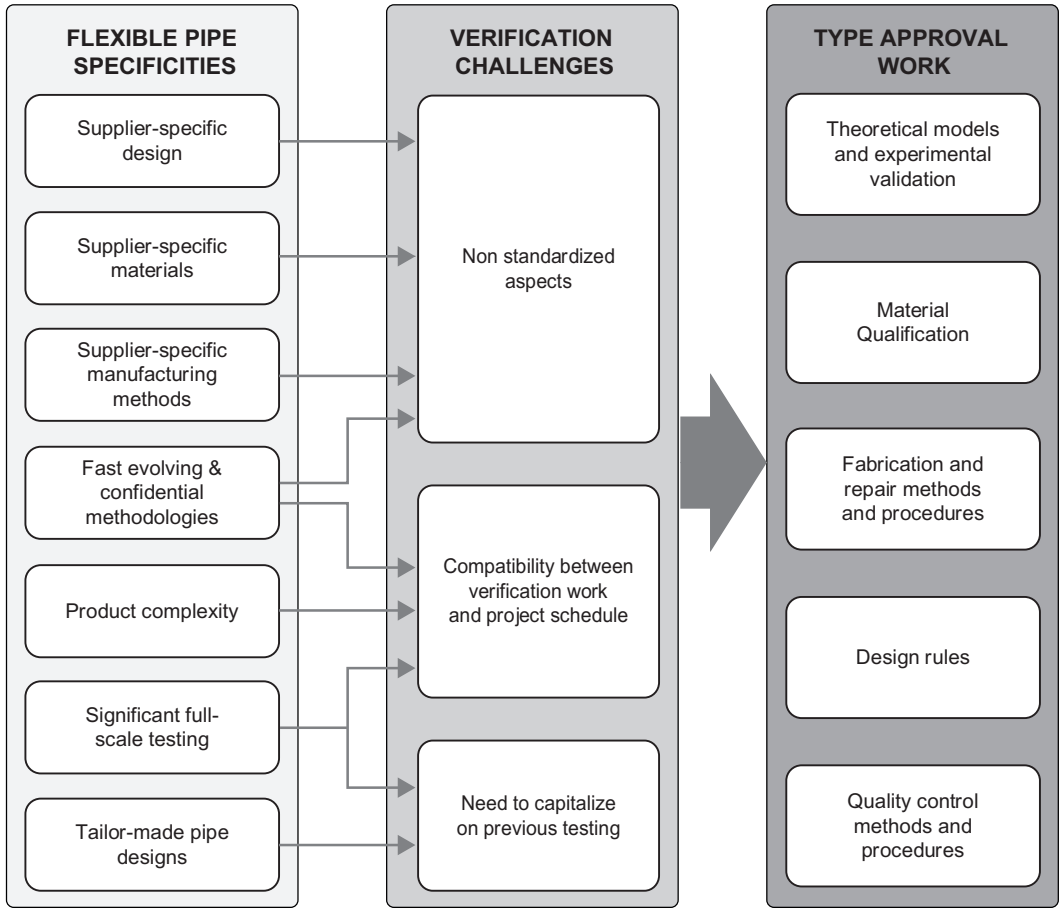
Examples of new technologies, or of events when the Q-FMECA process can be considered include:

- the development of a design methodology for a new failure mode
- the development of a new pipe / end-fitting concept
- the development of a new material
- the development of a new layer
- the development of a new manufacturing method
- the extension of a qualified range or enhancement of a qualified technology (design methodology, material, manufacturing capability, pipe concept) to an unqualified domain
- the qualification of a new material supplier.

The Society procedure for assessment of new technology qualification is described in App 1.

As a general rule, the final certificate and technical report associated to the qualification of a new technology is aimed for consolidation within the Type Approval process [4.3].

Figure 2 : Type Approval Certification in response to unbonded flexible pipe specificities



4.3 Type approval certification

4.3.1 In order to achieve an efficient assessment in the certification process, the Society's approach is to take advantage of an upstream work carried out in cooperation with the flexible pipe manufacturer. Such assessment related to the technology and not to a specific product is called Type Approval work and eventually leads to the issuance of a Type Approval Certificate (TAC) (see Fig 2).

The objective of the Type Approval work is to address the design methodologies of flexible pipes in the broadest sense of the term, namely considering at an equal level of importance the assessment of the strength prediction methodologies but also the manufacturing, the material qualification and procurement as well as the control methods and design rules.

In terms of normative requirements, the Type Approval certification is carried out based upon API 17J. The assessment of any additional requirement to API 17J would be covered outside the Type Approval certification (see [4.4]) unless specifically requested by the manufacturer to be considered during the Type Approval process.

The Type Approval certification work is detailed in Sec 2.

4.4 Project certification

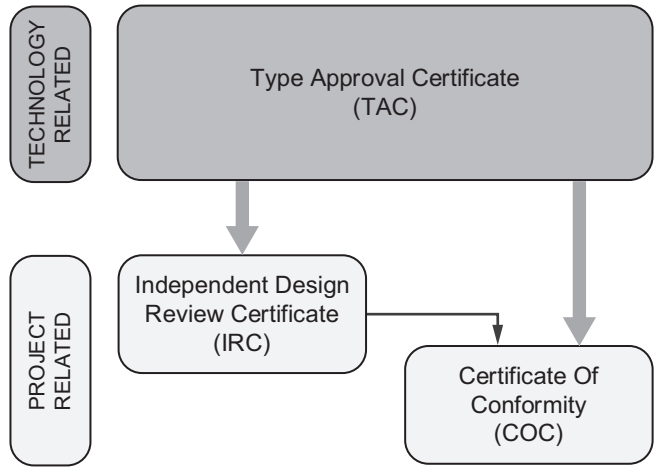
4.4.1 In a project-related phase, the proposed design is investigated versus end-user's specifications and methodologies covered by the Type-Approval Certificate, leading to the issuance of an Independent Design Review Certificate (IRC); In parallel, the survey during the actual fabrication, control and testing of the pipe is carried out, to verify conformity to procedures approved in the Type-Approval Certificate (TAC) leading to the issuance of a Certificate Of Conformity (COC).

This breakdown between generic Type approval certificate (TAC) and project-specific (IRC/COC) work contributes to fitting the projects time frame and capitalizing on previous qualification work thus avoiding to re-examine the technology related aspects for each project (see Fig 3).

Given the extensiveness of the scope of the Type Approval phase as described above, it naturally makes the Type Approval Certification a central element of the verification process.

The project certification work is detailed in Sec 3.

Figure 3 : Overview of flexible pipe verification scheme, Project Certification



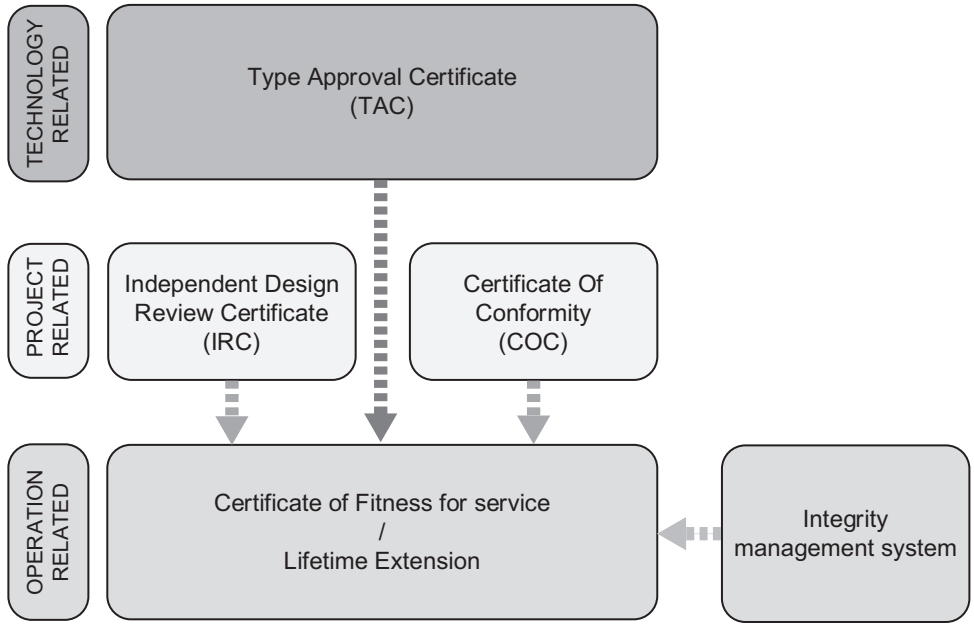
4.5 Operational management

4.5.1 At the end of the flexible pipe lifecycle or following an incident during operation, a re-assessment can be performed in order to certify that the line can still be operated safely and in accordance with end-user requirements (see Fig 4). The verification work is similar to the one carried out for project certification, except that the historicity of the line is integrated (e.g. actual loads, actual operating conditions, inspections/monitoring data, characterization of aged material properties) with a particular focus on the time-evolving degradation mechanisms.

The End user is expected to operate and monitor the flexible pipe system in accordance with project design basis and monitoring and maintenance plan, allowing to follow the product condition.

The verification work for condition assessment and lifetime extension purposes is detailed in Sec 4.

Figure 4 : Overview of flexible pipe verification scheme, Operational management

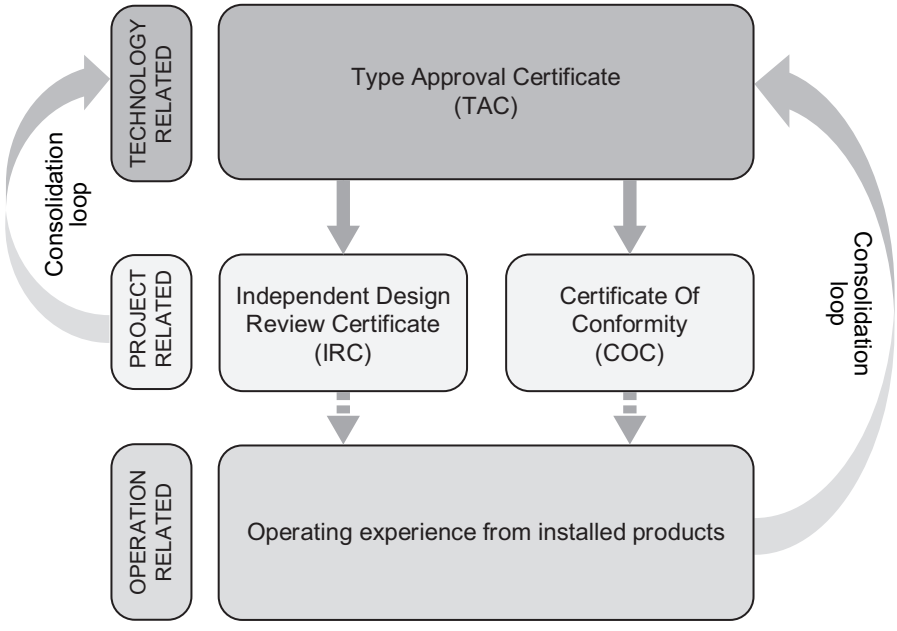


4.6 Operating experience feedback

4.6.1 As the technology matures, all the available source of operating experience feedback (e.g. Sureflex JIP Report) is considered in order to reinforce the Type Approval documentation. Examples of feedback can include unforeseen events such as failure mode with excessive probabilities of occurrence, or on the contrary confirmation that a new technology can be considered as field proven due to significant track record (see Fig 5).

In parallel, any technology-related work that may have been triggered by project-specific needs can be consolidated into the Type Approval documentation.

Figure 5 : Overview of flexible pipe verification scheme, Operating experience feedback



4.7 Summary of verification services and deliverables

4.7.1 The list of verification services for non-bonded flexible pipes is given below and summarized in Tab 1:

- Qualification of New Technology:

  When a Manufacturer develops a New Technology, the Society can assess and validate the qualification programme as well as its implementation and issue a Certificate of New Technology Qualification. For additional information, refer to [4.2] and App 1.

- Type Approval Certification:

  In order to provide a validation of the technology-related aspects of its products, a Manufacturer can request a Type Approval Certification. The deliverable is a Type-Approval Certificate (TAC) which is aimed at being regularly updated within the Type-Approval process. For additional information, refer to [4.3] and Sec 2.

- Statement of qualification status:

  During a tender phase, the flexible pipe Purchaser may request the Society to perform a gap analysis between the Purchaser technical requirements and the qualification status of each relevant design methodology, fabrication capability or material covered by the Type Approval Certificate. The deliverable is a Statement which identifies the already qualified aspects as per Type Approval Certificate as well as the aspects that would require supplementary qualification activities. For additional information, refer to Sec 3, [2].

- Project Certification:

  During the design phase of a project, the Society can be contracted by the Purchaser or the Manufacturer in order to assess the suitability of the flexible pipe design and manufacturing against the End-user's specifications and methodologies covered by the Type-Approval. The deliverables are an Independent Design Review Certificate (IRC) covering the design aspects as well as a Certificate Of Conformity (COC) covering the manufacturing of the project lines with their ancillary items. For additional information, refer to [4.4] and Sec 3.

- Operational management:

  In case of an incident during the operation of the flexible pipe or at the end of its initial lifetime, the Owner of the flexible pipe system may request from the Society a Third-Party review in order to state that its flexible pipe system still meets a sufficient safety level. The deliverable is a Certificate of fitness for service or of lifetime extension. For additional information, refer to [4.5] and Sec 4.

Table 1 : Overview of flexible pipe verification services

Product phase	Type of service	Contractor	Deliverable
Technology qualification and certification	Qualification of new technology	Manufacturer	Certificate of new technology qualification
	Type approval certification	Manufacturer	Type approval certificate
Pre-project	Statement of qualification status	Purchaser Manufacturer	Statement
Project	Project certification	Purchaser Manufacturer	Independent design review certificate and Certificate of Conformity
Operation	Operational management	Owner Operator Engineering	Certificate of fitness for service Certificate of lifetime extension

5 References

5.1

5.1.1 Society documents

Guidance Note NI 525 DT R01 E, Risk Based Qualification of New Technology - Methodological Guidelines, April 2020.

5.1.2 API documents

- API Specification 17J Fourth Edition - Specification for Unbonded Flexible Pipe, November 2014.
- API RP 17B Fifth Edition - Recommended Practice for Flexible Pipe, May 2014.
- API Technical Report 17TR2 First Edition - The Ageing of PA-11 in Flexible Pipes, June 2003.
- API Specification 17L1 2nd Edition - Specification for Ancillary Equipment for Flexible Pipes and Subsea Umbilicals, June 2021.
- API RP 17L2 2nd Edition - Recommended Practice for Ancillary Equipment for Flexible Pipes and Subsea Umbilicals, June 2021.
- API RP 17N 2nd Edition, Recommended Practice on Subsea Production System Reliability, Technical Risk, and Integrity Management, June 2017.
- API RP 17Q 2nd Edition, Recommended Practice on Subsea Equipment Qualification, May 2018.

5.1.3 ISO documents

ISO 9001:2015 - Quality management systems, Requirements.

5.1.4 Other documents

- OMAE2017-61916 - Verification scheme for unbonded flexible pipes: Definition, implementation and reflection of API 17J.
- Un-bonded Flexible Risers - Recent Field Experience and Actions for Increased Robustness, 4Subsea for PSA Norway, 0389-26583-U-0032 Rev.5.
- Flexible Pipe Integrity Management Guidelines & Good Practice (Sureflex JIP), J000621-00-IM-GL-001 Rev.1, Sept 2017.
- Lifetime extension for transportation systems, Norsok Y-002:2021.
- Lifetime Extension of Flexible Pipe Systems, IOGP Report 623 (2019).
- Handbook on Design and operation of flexible pipes, OC2017 A-001.

SECTION 2 TYPE APPROVAL

1 Main principles

1.1

1.1.1 The Type Approval work is an assessment related to the flexible pipe technology of a Manufacturer. It is therefore generic and not meant to be specific to a project or a pipe design.

The Type Approval Certification is structured around the review of the five following building blocks:

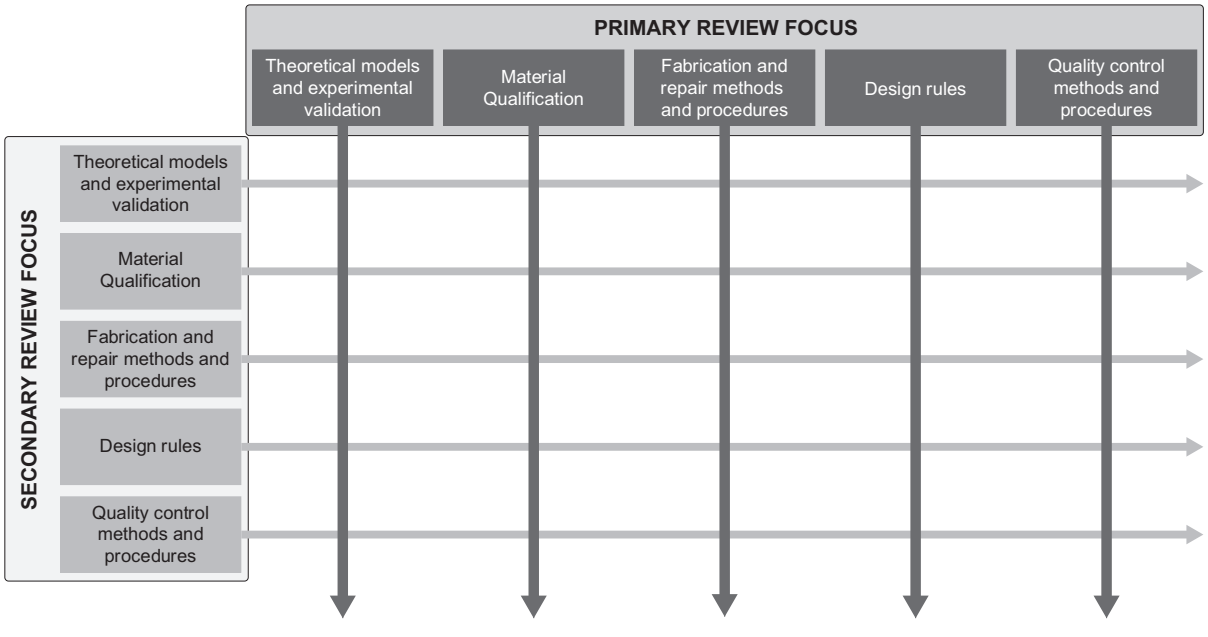
- Theoretical calculation methodologies and tools (theoretical analysis of the design) as well as their experimental validation and procedure for use in design (see Article [3])
- Material qualification dossiers (see Article [4])
- Methods and procedures of fabrication, including control, testing and repair (see Article [5])
- Manufacturer's design rules (see Article [6])
- Quality Control and Quality Assurance system (see Article [7]).

Even if the 5 items abovementioned are investigated separately from each other and covered by intermediate certificates, each influences the others. As a consequence, even when the review work is focused on a given item (e.g. a design methodology), all the other four items are indirectly addressed. This matrix review process embedded within the Type-Approval allows a robust verification (see Fig 1).

Some elements put forward by the Manufacturer for integration into the Type Approval (e.g. design methodologies, materials) may be part of completed or on-going new technology qualification programmes. The specific verification process for new technologies as well as their integration within the Type Approval work is described in App 1.

The Society Type Approval certification is consistent with the API 17J definition given to the IVA and its role: “Independent party or group, selected by the Manufacturer, who is responsible for the review and certification of the indicated product concept (e.g. pipe and end fitting concept) and flexible pipe, associated design, manufacturing methodologies and criteria, material qualification and prototype performance based on the technical literature, analyses, results and other information provided by the Manufacturer to establish the range of applicability”. The delivered Type Approval Certification Report corresponds to API 17J's Design Methodology Verification Report (refer to the first clause of [8.1]).

Figure 1 : Matrix review process within Type-Approval



The Type Approval Certification is the culmination of the assessment process described above. This process being by essence a long-lasting task, certificates or interim statements can be issued in order to demonstrate the progress of the certification, but do not substitute to the Type Approval Certificate in which the overall consistency is ascertained (refer to [8.1] for Type Approval deliverables).

2 Component and prototype testing

2.1 General

2.1.1 Due to their complex nature, the various number of failure modes involved as well as the use of tailor-made designs, flexible pipe products are prone to extensive qualification testing campaigns, see API 17B Section 7.

These tests can be performed at various scales (Small-scale, mid-scale or full-scale) and used either during Manufacturer's internal development campaigns or in a project phase in order to demonstrate the performances of the product to the End-user.

Prototype and material testing can be carried out for multiple purposes and it is common that a single test meets simultaneous objectives. Example of testing purpose include:

- the qualification of a new pipe concept
- the evaluation of the pipe performance against a targeted failure mode
- the evaluation of the pipe global characteristics (e.g. stiffnesses, overall heat transfer coefficient)
- the measurement of pipe in-situ local quantities (e.g. wire strain, local temperature profile across pipe section)
- the validation of a design methodology
- the qualification of a material in in-situ conditions
- the qualification of a manufacturing process
- the extension of the qualification range of a design methodology or pipe component / material
- the determination of a component property (e.g. wire S-N curve, polymer blistering resistance, corrosion tests).

2.2 Society involvement

2.2.1 Experimental evidence from testing is a key aspect of the Type Approval process as testing results can be consolidated into all building blocks of the Type Approval, whether it is prediction methodology validation, material or manufacturing qualification or design rules development.

2.2.2 As a consequence and as much as possible, Society shall be involved in the production of any experimental data meant to be considered for consolidation within the Type Approval, from sample manufacturing until test execution and prototype dissection, whenever relevant.

2.2.3 Exceptionally, if no IVA involvement was made possible (e.g. for experimental data collected before the initiation of the Type Approval process), a comprehensive testing documentation shall be produced, including as a minimum the sample manufacturing report, the test execution report and the prototype dissection report, whenever relevant.

2.3 Requirements

2.3.1 The test specimens shall be demonstrated to be designed and manufactured in accordance with the methods in force. Exception is made for early qualification phases of new products for which preproduction samples can be accepted.

2.3.2 The Society will verify that a quality plan, or equivalent, is established for prototype samples manufacturing, testing and dissection. This will identify the relevant fabrication and control procedures, the intended attendance / witnessing by the manufacturing, control and development project team personnel, and include the intended Society involvement. The Society will then verify that the fabrication, control and testing follow the procedures without significant deviation and that acceptance criteria are established to quantify acceptable deviations.

2.3.3 Regarding the manufacturing of the samples, a sufficient involvement of the Society through inspection / auditing will be determined through quality plan (or equivalent) mark-up prior to the start of the manufacturing process of samples fabrication and preparation for testing. This involvement will aim at observing that the process embodying the assessed material is stable and reliable, and at concluding that the test samples can be considered representative of the future project production. Such stability has to ensure that no significant variation of properties would occur throughout the manufacturing process.

2.3.4 Whenever relevant, the test procedure shall include objective acceptance criteria.

2.3.5 Regarding the test execution, the Society (Inspector or engineer) will review the test procedures, verify the calibration certificates of the test equipment and attend to the test as per agreed involvement in Quality Plan / Inspection and Test Plan (ITP) (or equivalent). As a minimum, the following steps shall be registered as witness points on relevant ITP:

- prototype pressurisation (when relevant)
- load block variation (when relevant)
- relevant test main points / steps
- dissection.

2.3.6 In the case of a new machine, factory, material or type of test, the quality plan mark-up can be made more stringent than for other cases due to the lack of experience of the production operators, test engineers.

2.3.7 For Mid-scale and Full-scale tests, the test documentation to be produced by the Manufacturer shall include, as a minimum:

- the tested product datasheet
- the test sample manufacturing data book
- the test procedure
- the test report
- the analysis report, if relevant
- the dissection report
- any complementary investigation report (laboratory investigations, Finite Elements analyses).

2.3.8 For Small-scale tests, the documentation to be established shall include, as a minimum:

- test specimen(s) material certificates
- the test procedure
- the test reports
- the raw material specification and raw material supplier(s) used for the test samples
- the evidence of attendance of an IVA inspector during the tests
- any complementary expertise of the specimens (e.g. Ultrasonic Testing, Magnetic Particle Inspection, corrosion scale analysis, micrographies, residual stress measurements).

2.3.9 After each inspection / witnessing activities, an inspection report will be issued, detailing the scope of the inspection as well as the objective conclusions.

2.3.10 In case a test acceptance criterion would fail to be met, the Manufacturer should perform a root cause analysis in order to identify the origins of the non-conformity and assess its consequences. The analysis report of this non-conformity shall be presented to the Society for assessment, the potential impact of this non-conformity on the Type Approval being subject to the identified cause (e.g. inaccurate design methodology, manufacturing non-conformity, component material defect, test execution error, testing artefact, unexpected failure mode) and consequences.

3 Design methodologies

3.1 General

3.1.1 In order to rationalize the high costs involved during flexible pipes qualification campaigns based on full-scale testing, the validation of a design methodology allows to consolidate historical qualification campaigns into a range of products for which a predictive methodology can be safely applied without requiring additional testing costs.

The certification of the design methodologies is deemed to be at the core of the Type Approval process. Indeed, even if this work generally initiates on a theoretical basis compared with prototype testing, the link with materials qualification and manufacturing process is always present. It is worth recalling that API 17J considers that a design methodology shall encompass the following:

- a theoretical model
- an experimental verification of the theoretical model
- a calculation procedure for pipe design
- an assessment of the impact of manufacturing
- a standardized list of material properties and qualification tests.

For practical purposes, the assessment of the overall pipe design methodology is split into the assessment of multiple design methodologies being independently scrutinized and defined by their own range of applicability. These methodologies can be linked to a failure mode, a failure mechanism, a layer, a component but also to the prediction of intermediary design data. In the overall pipe design methodology certificate, all the conclusions of the individual assessment of the design methodologies are gathered.

In the end, the Type Approval concept allows to merge all these design methodologies and eventually certify that all the pipe layers and components are satisfactorily covered. By definition, the Type Approval work is largely focused in priority on the design methodologies related to local pipe design (i.e. linked to the detailed analyses of the components of the cross-section) as the global pipe design (i.e. flexible pipe in-field configuration analyses) is not directly related to technological aspects, except if directly coupled with local design methodology.

The following non-exhaustive list presents some examples of basic design methodologies that are considered important to be covered in a Type Approval. The difference is made between failure models which objective is to predict a limit state of the flexible pipe and the behavioural models which objective is to provide an intermediate design quantity.

- Failure models:
  - burst
  - damaging pull
  - hydrostatic collapse
  - crushing collapse
  - overbending
  - end-fitting anchoring capacity
  - lateral buckling of tensile armours
  - bird-caging of tensile armours
  - pressure sheath excessive strain and creep
  - fatigue and corrosion-fatigue of tensile armours in pipe body
  - fatigue and corrosion-fatigue of tensile armours in end-fitting
  - fatigue and corrosion-fatigue of pressure armours
  - pipe slippage during installation.
- Behavioural models:
  - determination of pipe basic stiffness properties, including non-linear moment-curvature relationship
  - determination of stress and strains in all pipe layers under axis-symmetric loadings
  - determination of stress and strains in all pipe layers under axis-symmetric and bending loadings
  - determination of the composition of annulus environment
  - determination of the temperature field in the pipe and overall heat transfer coefficient
  - determination of the flow induced pulsation onset velocity.

3.1.2 In order to validate a given design methodology, a systematic approach is followed:

- as a first step of the review, the theoretical model is assessed (see [3.3]).
- in a second step of the review, the experimental validation of the theoretical model is scrutinized (see [3.4])
- in a third step of the review, the calculation procedure to be used for pipe design (i.e. the design methodology) is assessed (see [3.5])
- in a fourth and final step of the review, the conclusions of the assessment of the design methodology including its range of use are issued through a technical report, possibly supplemented by a Certificate.

The verification of the design methodologies presented in this Article is an important element of the Type Approval process, but it should necessarily be complemented by the review of the Manufacturer's design rules and qualification of materials. Indeed, it should be observed that all the failures modes are not necessarily covered by a design methodology, as alternatively the design against a given failure mode can be guaranteed by construction (e.g. pipe bore free flooding to avoid collapse or lateral buckling during installation) or material qualification (e.g. choice of carcass material to avoid corrosion under a specified bore environment). These aspects are presented in Articles [4] to [7].

3.2 Validation dossier

3.2.1 The minimal documentation to be provided by the Manufacturer for the validation of a design methodology includes:

- A theoretical report, describing the phenomenon assessed as well as the theoretical model considered to predict the limit state or the quantity scrutinized
- An experimental report (or set of reports) collecting all the experimental evidence put forward by the Manufacturer regarding the assessed phenomenon
- A correlation report showing the comparison between the experimental results and the theoretical model predictions
- A design instructions report describing how the developed model is to be used during engineering studies
- A packaging report describing the consolidation of the design model into a specific tool (e.g. spreadsheet, software)
- The range of applicability pertaining to the scrutinized methodology, as targeted by the Manufacturer
- Whenever relevant, additional documentation such as technical literature or Manufacturer's track record can be added to the validation dossier.

3.3 Theoretical model

3.3.1 As part of the review of the theoretical model, a special attention is paid by the Society to:

- The nature of the theoretical model:

  Depending on the complexity of the problem to be addressed and the level of optimization to be reached, the theoretical model can be of various natures from simple closed-form expressions to a multi-physic numeric calculations.
- The physical description of the phenomena involved and the relevancy of these phenomena with respect to the failure mode or physical quantity to be estimated.
- The simplifications and assumptions of the model as well as their impact on the model predictions.
- The limitations of the model due for instance to lack of experimental validation, over-simplifications or non-inclusion of some phenomena;
- The number of model input parameters:

  The total number of input parameters of the model shall be identified. At the stage of the definition of the design calculation procedure, the design values to be assigned to these parameters shall be clearly established.
- The classification of model input parameters:

  The nature of the input parameters shall be identified. In particular, the distinction between varying parameters (e.g. geometrical or material data) and frozen model parameters (e.g. calibration data) shall be made.
- The calculation of intermediary variables:

  The study of such variables can be useful to better understand the model and/or provide intermediate validation elements.
- The model sensitivity to the input parameters:

  Parametric model runs should be studied to demonstrate the suitability of the model in a given range of use.
- The behaviour of the model:

  As much as possible, the physics of the model should remain understandable. In particular, the trends observed by the parametric runs should be explainable and/or experimentally observed.
- The stability of the model:

  Together with the need for optimized methodologies, the design models tend to be more complicated by integrating non-linearities (e.g. material laws, large displacements, contacts, friction) and using numerical solving methods. In this context, the stability of the theoretical models in their whole range of use should be studied in order to identify potential risks of non-convergence or unexpected results.
- The need for calibration of the model:

  Depending on the degree of simplification of the model, the values of some parameters may need to be calibrated based on empirical data.

3.4 Experimental validation

3.4.1 As part of the review of the experimental validation of the theoretical model, a special attention is paid by the Society to:

- The respect of the testing requirements, as given in [2.3].

- The scale of the experimental validation:

  The experimental validation material can be based on small-scale testing, mid-scale testing, full-scale testing or combinations of all of these. As a general rule, for the above referenced failure and behavioural models, there are very few cases where a full-scale campaign test can be avoided in order to certify a design methodology.
- The test protocols:

  As a minimum it should be verified that the recommendations put forward in API 17B are followed wherever applicable.
- The test specimens:

  If for some reasons the design or manufacture of the test specimen does not comply with the methods in place (e.g. use of a leftover sample, simplified cross-section, non-conformity during manufacturing), it shall be demonstrated that the limit state / behaviour scrutinized is unaffected by this.
- The representativeness of the experimental set-up:
  - A special attention is paid to the loads and boundary conditions of the experimental set-up with respect to actual offshore conditions, this point being even more essential for mid and small-scale testing for which the estimation of representative loads and boundary conditions may be difficult.
  - The specific case of full-scale fatigue testing is scrutinized with care since contrary to most other full-scale tests, the test loads do not coincide with offshore loads due to the need for test acceleration. Under these accelerated test conditions, the risk of modifying the real failure modes should be estimated (e.g. creation or suppression of failure modes).
  - The full-scale testing artefacts.

    Even if full-scale testing is the most representative experimental validation, the test rig can still suffers from testing artefacts such as short length effects or unrealistic boundary conditions. Such effects need to be identified and considered by the Manufacturer in the model validation as much as possible.
- The validating tests stopping criterion:

  When the objective of a test is the validation of a theoretical model, two categories of tests can be foreseen: destructive tests and non-destructive tests.
  - For Type Approval validation of models predicting failure modes, destructive tests are deemed to be strongly preferable as they demonstrate that the actual observed failure mode is the one predicted and allows establishing the safety margins embodied by the model.
  - For Type Approval validation of behavioural models or in complement of the aforementioned destructive tests, non-destructive tests are valuable provided that a large representative range of loading conditions is investigated and that the test samples are properly instrumented.
- The intermediate validation:

  The validation of a failure model based on destructive testing is carried out through the comparison of an ultimate experimental value (e.g. burst or collapse pressure, number of cycles to failure) with the value predicted by the model. In parallel, in many instances, some elements of validation of the model can be provided through intermediate physical variables which experimental values can be obtained by a specific instrumentation of the sample. Even if these intermediate variables do not demonstrate the final failure mode, they allow gaining confidence in the model predictions. Such validation is particularly important when the scrutinized failure mode cannot be reached experimentally (rig limitations, precedence of another failure mode in the conditions of the test) or when the model relies on a high number of parameters. Some examples of intermediate variables include ovality measurements (crushing/collapse models), curvature measurements (tension-bending tests), strain measurements (axis-symmetric behaviour and fatigue models) or annulus fluid composition measurements (permeation models).
- The number and extent of experimental data:

  The range of loading conditions (loads, boundary conditions, environment), geometries and materials investigated should be duly taken into consideration for Type Approval assessment.
- Any experimental data discarded for model validation. The exclusion of this data shall be duly justified by the Manufacturer.
- The outliers, for which a significant deviation between the test results and the model prediction are observed. An explanation related to these outliers should be provided by the Manufacturer.
- The modelling of the validation test: The first step of comparing experimental values with predicted values is to run the model for the specific test sample and conditions assessed.
  - Regarding the choice of the value of the input parameters, the use of the test actual values (e.g. geometrical as-built values, real material characteristics, loadings or annulus composition actually measured …) shall be used whenever possible. If impossible, most probable values should be used instead. The non-respect of this clause can lead to the establishment of non-conservative design models (see Fig 2).

- All the input data considered in the modelling of the validation test shall be made available to the Society.
- In order to confirm the good implementation of the model, input data or to assess parameter sensitivity, the Society may conduct independent analyses (analytical, Finite Elements).

- The correlation between model predictions and tests results: For each relevant experimental data (e.g. test failure point, intermediate measurements, …), a comparison shall be carried out between the predicted value, calculated as indicated in the previous point, and the measured value, taking into account any relevant measurement uncertainties. For all the test results, it is to be ensured that the model predictions are conservative in themselves, thus meaning that the use of the API 17J utilization ratios as a test acceptance criterion is not acceptable to validate a design methodology and demonstrate a real margin. If the raw model predictions have been a posteriori corrected by a calibration factor to better match the experimental data, the calibration process shall be duly explained.
- The scatter of the model predictions compared to experimental data, as an indication of the model accuracy. Some examples of correlation plots are shown in Fig 3.

Figure 2 : Use of actual data

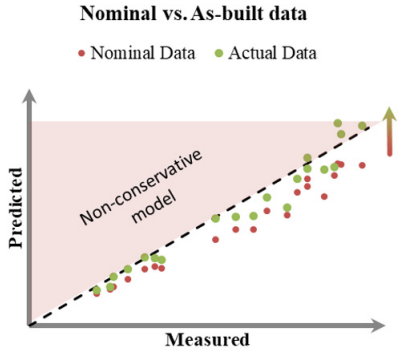
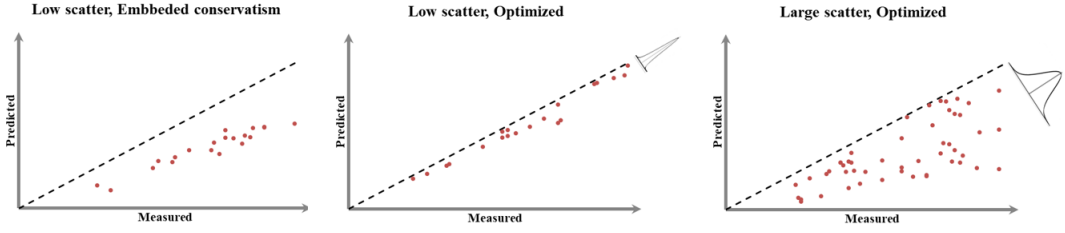


Figure 3 : Correlation plots



3.5 Calculation procedure

3.5.1 During the review phase of the calculation procedure, a special attention is paid by the Society to:

- The user's interface:
  - In order to be useable by the engineering departments and allow having a frozen approach for certification, the design methodologies developed by R&D departments shall be integrated in spreadsheets or computer programmes, identified by the version number that the Type Approval Certification covers.
  - It shall be ensured that the nature of the input and output data are well documented to avoid user's inputting errors.
  - Any parameter frozen in the model and identified as such during the validation procedure shall not be modifiable by the user.
  - All the input data of the methodology shall be explicitly stated in the output report.
  - A particular attention is paid to the design methodologies based on finite elements calculations as this method can be difficult to standardize and certify due to the high number of parameters involved. The Type Approval Certification request the FE models to be generated by validated pre-processing scripts in order to minimize the number of parameters, reduce modelling errors and allow for a standardized certifiable modelling methodology.

- The determination of the design data: the design methodology shall clearly indicate the design data to be considered by the user. For example, the consideration of the manufacturing tolerances combination, the design conditions or load cases to be studied should be identified.
- The safety margins: the way the safety margins are applied on top of a failure point predicted by a methodology (e.g. on loads, resistances) shall be defined by the Manufacturer, with a particular focus on highly non-linear models. Several ways of considering safety margins can be foreseen: Choice of conservative design values, choice of conservative design scenarios, application of global safety factors or application of partial safety factors. In all cases, it shall be demonstrated that the overall design margin is in accordance with the maximum utilization levels defined by API 17J for the assessed failure mode or component.

3.6 Assessment report

3.6.1 In conclusion of the verification work, a detailed assessment report is issued. This report includes:

a) The description of the theoretical model

b) The description of the experimental validation material

c) The description of the correlation between test results and model predictions

d) The description of the design procedure, including the choice of design data and application of safety margins

e) The Society position regarding the assumptions, uncertainties and limits of applicability of the methodology

f) The Society position regarding the range of applicability of the design methodology, also called qualified range or certified range (see Tab 1). The definition of this envelope is the logical outcome of all the aforementioned assessment work. As each case is different, the establishment of such ranges necessarily involves sound engineering judgment. The following basic principles are always be observed:
   - The parameters that characterize the range are defined based on the physical model assessed. The total number of parameters is chosen to be sufficiently high to safely establish the limits of the design methodology, but remaining intelligible. Basic parameters include:
     - Geometrical quantities such as pipe internal diameter, armour sizes, armour laying angle, carcass profiles, sheathes thickness
     - Material related quantities, such as material grades
     - Loading related quantities, such as internal pressure, external pressure, temperature, bending radius, water depth
     - Manufacturing requirements such as tolerances to be respected, specific process to be applied, specific machine designation to be used
     - Annulus environment requirements, such as pH, CO_2 fugacity or H_2S fugacity
     - More refined parameters to properly outline the design methodology such as pipe internal diameter x Internal pressure, contact pressures, component thickness / pipe internal diameter.
   - The range is structured around the experimental material used for the validation of the model. The extrapolation of this testing range towards a qualified range largely depends on a lot of aspects that are taken into account such as:
     - The confidence in the theoretical model
     - The robustness of the test database
     - The need for calibration of the methodology
     - The levels of safety margin considered for design.
   - In case several sub-families clearly emerge from the review of the data, they can be addressed by separated qualified ranges (see Tab 2).
   - The qualified range aims at a reasonable trade-off between a too restrictive domain of use of the methodology (e.g. limiting the use of the methodology to tested pipes only would disregard that a prediction model exists and may involve unnecessary testing costs) and a too wide domain of use of the methodology (e.g. by allowing pipe designs or loadings clearly different from the ones actually tested).
   - The procedure for the establishment of the range of applicability of a design methodology follows the API 17B "Qualification by Similarity Assessment" general principles as it allows qualifying pipe designs without the requirement of prototype testing, based on the comparison with previously qualified pipe designs. The implementation is however different since the process also takes account of the design methodology and considers case-specific parameters that generally differ from the ones given in API 17B. For example, the API 17B recommended scaling of +/- 2 inch from the tested pipes is not systematically applied for the definition of the range of applicability of a design methodology.

g) Recommendations regarding further work required to further extend the range of applicability of the methodology, if any.

Table 1 : Example of certified range

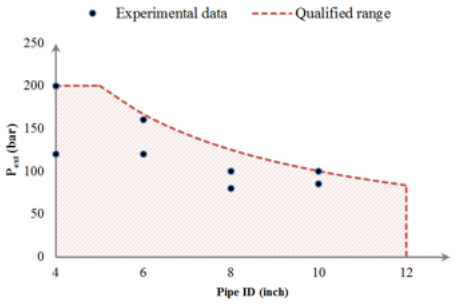
Parameter	Range	
Pipe Family as per API 17B	Family I, II, III	
Pipe Internal Diameter	4″ to 12″	
Tensile armour material	Grades XX1, XX3	
Tensile armour size	Width ≤ 10 mm Thickness ≤ 4 mm	
Annulus condition	Seawater flooded	
External pressure P_{ext}	≤ 200 bar	
Pipe Internal Diameter x P_{ext}	≤ 1000 inch.bar	
Manufacturing	As per procedure XXX	

Table 2 : Example of certified range with sub-families

Parameter	Range	
Pipe Family as per API 17B	Family I, III	Family II
Pipe Internal Diameter	4″ to 12″	6″ to 8″
Tensile armour material	Grades XX1, XX3	Grades XX1, XX3
Tensile armour size	Width ≤ 10 mm Thickness ≤ 4 mm	Width ≤ 10 mm Thickness ≤ 4 mm
Annulus condition	Seawater flooded	Seawater flooded
External pressure P_{ext}	≤ 200 bar	≤ 100 bar
Pipe Internal Diameter x P_{ext}	≤ 1000 inch.bar	–
Manufacturing	As per procedure XXX	As per procedure YYY

4 Material qualification

4.1 General

4.1.1 Flexible pipes are used to convey fluids at high pressure, typically several hundreds of bars, and high temperature, up to 150°C, or even above. The fluids transported include gas, oil, water, carbon dioxide (CO_2), hydrogen sulphide (H_2S), and various types of biocides or corrosion inhibitors. The different pipe layers and end-fitting have to fulfill their functions while withstanding all manufacturing steps, the factory acceptance testing, the installation, the offshore leak test and service life conditions.

Due to ever challenging project conditions or to the need of optimization of pipe structures, suppliers of flexible pipes regularly undertake qualification of new materials or carry out development aiming at extending the domain of use of an existing material.

Main materials covered are the materials of the following flexible pipe components:

- interlocked steel strips for internal carcass layer
- polymer layers such as polyethylene, crosslinked polyethylene, polyamide and polyvinylidene fluoride, to be used as pressure sheath, intermediate sheath or outer sheath
- steel reinforcement strips / wires to be used for pressure or tensile armours, and generally made of high strength carbon steels
- anti-wear tapes
- high strength tapes / anti-buckling tapes
- insulation materials
- end-fitting materials, including steel, polymers, elastomers and epoxy resin.

The assessment of a given material follows requirements set forth in API 17J resulting in the verification of:

- procurement and raw material specification
- material dossier documenting material properties and chemical compatibility
- processing at plant, e.g. polymer extrusion, carcass profiling, or armour wires laying
- behaviour of the material in its environment accounting for other layers and end-fitting
- allowable envelope of utilisation of the material defined in design rules.

The Type Approval certificate and report include a list of materials covered, as assessed, together with the range of applicability, validated in terms of e.g. internal diameter, internal and external temperatures, internal and external pressures, internal fluids composition, and relevant limitations.

The requirements and verification procedure for material qualification are described in [4.2] [4.10].

4.2 Identification and intended range of use

4.2.1 When proposing to use a new material for incorporation into the Type-Approval process, the Manufacturer shall document the nature of the material (physical / chemical, microstructure, patents, etc.), a provisional procurement specification, the intended function in the flexible pipe structure, and the intended purpose / range of use.

The intended range of use / service answers End-Users needs and requirements, described in their purchasing specification, such as described in API 17J Annex B, and in summary shall include the relevant parameters such as:

- pipe internal diameter
- internal and external min/max temperature range
- internal (bore) and external (water depth) extreme pressure range
- application system (static flowline or jumper, dynamic jumper or riser)
- bore fluid (gas, oil, water, phase)
- service conditions (H_2S, CO_2, H_2O, pH).

Such a range shall be proposed by the Manufacturer, in relation with the intended market needs and possible limitations found in their assessment phase.

In the case of addition of a material grade that is presented as close to an already qualified grade, or in the case of a new supplier for an already qualified grade, gap analyses are required. The qualifying tests to be selected will aim at proving both the compliance with API 17J and the similarity between the existing and new grades, results serving to quantify the gap. Tests may be avoided and results considered identical to the grade already validated, when justified / documented by literature, Manufacturer experience or supplier data.

4.3 Procurement

4.3.1 The following points shall be documented:

- raw material identification, related patents, sub-supplier and chain of transformation at the supplier and sub-supplier plant if / when relevant
- raw material specifications (in line with API 17J Tables 17 and 18), justification of control and tests required from Manufacturer, receiving / acceptance procedure by Manufacturer
- supplier's QA System Certificate and Certificate 3.1 (EN10204:2004)
- list of suppliers and sub-suppliers qualified by the Manufacturer
- supplier and sub-supplier assessment report and regular audit reports from Manufacturer.

4.3.2 Raw material specifications are to be prepared for regular procurement for projects manufacturing, taking into account the necessary performance of the material in its function in the flexible pipe.

4.3.3 Dispersions in procured material characteristics shall be assessed in order to confirm that product expected performance are achieved.

4.3.4 The raw material procurement will be evaluated by the Society. The purpose of this evaluation includes the following:

- identification of the material, its scientific name, patent if any
- understanding of what processes are carried out at supplier and sub-suppliers plants
- understanding of what quality assurance level is reached there to ensure adequate response to the Manufacturer's purchasing requirements

- agreement that those requirements are sufficient to ensure the stable supply of the new material with reliable properties: no significant variation of properties should occur throughout the manufacturing process at the supplier plant (in particular Hydrogen-Induced Cracking (HIC) / Sulfide Stress Cracking (SSC) test resistance for sour service wires)
- agreement on the acceptability of pre-qualification test results if relevant.

4.3.5 A programme of inspection / audits by the Society will be organised and scheduled with the Manufacturer and its supplier, as required.

4.3.6 Reports of inspection / audits will be issued to support the overall verification report / certificate.

4.4 Manufacturing process

4.4.1 With respect to the material transformation carried out in the plant, the main manufacturing process that are assessed by the Society, related to each flexible pipe layer are referenced in Tab 3. A specific attention is drawn to the following different situations:

- For a metallic grade (wire, pressure armour, carcass etc.), the manufacturing process mainly concerns the forming while re-coiling, laying, and the welding/control aspects. Some specific design characteristics may also need to be assessed. For example, the properties of the interlocked carcass in order to validate profile shape, inertia and final material characteristics after cold forming, the wires accumulated plastic strain, the wires local stress profiles (residual and trapped elastic stresses) or the surface conditions of the wires (characterization of surface defects can be required for fatigue performance assessment if any). More generally, the impact of the manufacturing process on the in- situ wire performance should also be considered.
- For a plastic grade which is developed and extruded (followed sometimes by a cross-linking process) at the plant of flexible pipe Manufacturer, the manufacturing process concerns the overall steps of extrusion process including the control methods on raw (at receipt, during storage in the Manufacturer's warehouse and just prior to use deemed necessary) and extruded products, including the repair process.
- For the tapes (in particular high strength tapes) and epoxy in the end fitting, some specific design characteristics also need to be assessed.

4.4.2 The introduction of a material in the pipe body impacts the End-Fitting as well and the End-fitting mounter training and shall be included in the qualification programme, as necessary.

4.4.3 Transformability of the procured materials in the various manufacturing process machines, to reach the desired results and satisfy the desired function in the flexible line, and stability of the process within identified tolerances, selection of tools etc., to have reproducible and reliable results, is to be secured through adequate procedures, work instructions. The Manufacturer shall establish that no significant variation of properties can occur throughout the manufacturing process, hence that any section cut out may be acceptable as representative for testing.

4.4.4 Important parameters have to be recorded as necessary. Required controls to ensure all fabrication (and repair) parameters and end-results within qualified tolerances are also to be defined well in procedures, recording formats available.

When assessing a new grade close to a qualified one, a manufacturing trial may need to be performed, based on Q-FME(C)A outcomes, with the industrial tool in order to validate the manufacturing process, and to provide new material grade samples for the material qualification. It shall be ensured that the proposed process, similar to the one of the already qualified grade, is adequate, showing no particular anomaly nor difficulty.

4.5 Small scale testing

4.5.1 API 17J lists the minimum tests to be performed to identify material properties:

- §6.1.2 and Table 12 for polymers,
- §6.1.5 and Table 14 for antibuckling tapes
- §6.1.3 and Table 13 for metallic strips/wires
- §6.1.4 for end-fitting material.

4.5.2 The required tests shall be performed through the procedures defined in:

- Table 15 for polymers
- Table 16 for metallic strips/wires
- §6.2.5 for end-fitting materials.

Table 3 : Main manufacturing processes to be documented

Manufacturing Process Control Point to be documented **(6)**	Carcass	Pressure Sheath	Inner Liner (Smooth Bore)	Pressure Armour	Tensile Armour	Antiwear tape	Antibuckling tape	Insulation Tape	Intermediate **(7)**, Outer and Abrasion Sheath	End-Fitting
Raw material handling	X	X	X	X	X	X	X	X	X	X
Profiling	X									
Extrusion **(1)**	X **(5)**	X	X **(2)**						X	
Spiralling			X **(2)**	X						
Armouring					X					
Winding						X	X	X		
Welding (Welding Procedure Specification (WPS) / Welding Procedure Qualification Record (WPQR))	X			X	X	X	X	X		X
Reeling	X	X **(4)**	X **(2)** **(4)**	X	X	X	X	X	X **(4)**	
End-fitting mounting / sealing		X	X							X
End-fitting mounting / anchoring				X	X **(3)**	X	X	X		X
End- fitting mounting / resin injection										X
Non-conformance	X	X	X	X	X	X	X	X	X	X
Repair activity	X	X	X	X	X	X	X	X	X	X
Quality assurance / quality control documentation	X	X	X	X	X	X	X	X	X	X

(1) Includes specific extrusion-related process if relevant, e.g. removal of plasticizer, cross-linking, stress relieving, or any other essential parameters of process requiring validation

(2) Particular requirements for smooth bore pipes apply for inner liner extrusion, reeling, and spiralling the pressure armours

(3) Shall include various processes associated with tensile armour wires folding, forming, and aiming at ensuring proper axial load transfer between the flexible pipe and end-fitting for extreme as well as fatigue loadings

(4) As per API 17J, folding likelihood is to be assessed considering sheath diameter, sheath thickness and drum diameter. This risk is relevant during layer production as well as during handling.

(5) As per API 17J, the Manufacturer shall document that during extrusion the carcass pitch is within the specified tolerances.

(6) Interference between the different processes which may impact characteristic of other layers is to be accounted for (e.g. welding, cutting …).

(7) Procedures and tools used for perforation of intermediate layers for gas-venting purposes shall not induce defects in underlying layers. Perforation by melting with heated tooling is preferred.

4.5.3 The above list of required small scale tests may be complemented based on the conclusions of a Q-FMECA (see App 1).

4.5.4 The tests shall be performed with samples representative of materials in layers produced by the Manufacturer (extruded polymers, profiled carcass samples…), to the extent required to cover the intended range of use. The underlying layer on which plastic sheath is produced may impact the polymer performance.

4.5.5 When the material is proposed to be used in a position / function where slippage, or lack of slippage, may be detrimental, friction properties shall be established for related pairs of materials (considering the relevant parameters: temperature, ageing, contact pressure…).

4.5.6 The fatigue performances of steel wires represent a crucial aspect of the Type Approval of dynamic pipes. Significant fatigue testing campaigns are to be launched aiming at covering the different combinations of wire grades and environment (air, fatigue-corrosion) that may be encountered.

4.5.7 Considering the high mechanical characteristics of the steel wires used in flexible pipes (e.g. Specified Minimum Yield Stress (SMYS) and Ultimate Tensile Stress (UTS) much higher than steel traditionally used for metallic construction or for rigid pipelines) the resistance vis-à-vis H_2S is particularly scrutinized for sour conditions with respect to both Hydrogen-Induced Cracking (HIC) / Sulfide Stress Cracking (SSC) test failure mechanisms. The allowable envelopes of utilisation of wire grades constitute an important design rule to be evaluated as part of Type Approval activities.

4.5.8 The polymer material properties are to be documented over the domain of use. In particular, the long-term behaviour and ageing effects are to be investigated, refer e.g. to API 17TR2 regarding the ageing of polyamides 11.

4.5.9 Whenever a polymer material is to be used in supercritical fluid environment, relevant tests shall be carried out in order to guarantee the material integrity throughout the service life, in particular the chemical compatibility shall be validated in the representative pressure and temperature conditions (e.g. CO_2 supercritical dense phases).

4.5.10 The Society assessment will consist in a combination of documentary review, including test procedures as well as third party inspection / witnessing, as described in [2.3].

4.6 Full and mid scale testing

4.6.1 In addition to small scale laboratory tests, it is important to document the correct behaviour of the material being qualified in its actual environment, taking into account in particular the different interactions with other layers seen by the material in the current length and in the end-fitting area.

4.6.2 Examples of interactions difficult to be captured in small scale testing, hence the need of mid-scale / full-scale tests, are given hereafter:

- high contact pressures combined with relative displacements between layers
- multiaxial loadings
- combined pressure loadings (constant or transient), temperature loadings (constant or transient), and mechanical loadings / restraint (leading to creep or relaxation effects)
- friction characteristics and sliding resistance of the flexible pipe interface layers during installation or service life
- pressure sheath sealing system in end-fitting.

4.6.3 The list of required full scale tests shall be established as required by aspects mentioned above, other design change situations when relevant, and based on a Q-FMECA findings (see App 1) and relevant considerations to manage risks as low as reasonably practicable.

4.6.4 The test prototypes of flexible pipe length and end-fitting shall be representative of the design intended to be delivered to end users.

4.6.5 The Manufacturer may elect to use a mid-scale sample, partly representative of the flexible pipe with the assessed material, when / if the simplification does not impair the purpose of the test regarding the material function in the pipe. This leads to so-called Mid-Scale Test instead of Full Scale Test.

4.6.6 The requirements associated to the testing activities are described in [2.3].

4.6.7 Depending on the test outcome, complementary investigation may be carried out or required by the Society, such as numerical Finite Element Analysis (FEA) study or laboratory investigations. This shall also be documented for the Society review at this stage.

4.7 Quality assurance

4.7.1 The testing quality plan associated to the testing activities shall be in accordance with the requirements given in [2.3].

4.8 Design rules implementation

4.8.1 In accordance with API 17J, design methodologies account for the effects of wear, corrosion, manufacturing processes, dimensional changes, pressure sheath thickness reduction due to creep into gaps, and ageing (due to mechanical, chemical, and thermal degradation) in all layers, unless the pipe design is documented to not suffer from such effects. Consequently, the material properties (determined during qualification Small Scale Test (SST)) used for design of flexible pipes are to be well implemented as input to the Manufacturer design software and methodologies predicting the behaviour of the flexible pipes and its relevant limit states.

4.8.2 With respect to the appropriate selection of polymers and steel grades inside or in contact with the pipe annulus, the methodology used for determining the annulus conditions (gas / liquid phases, chemical composition, presence of water, temperature …) is to be assessed. In accordance with API 17J, the cases of pipe annulus flooding by condensed water from the bore and outer sheath breach are to be considered. Such methodology is assessed using the principles described in Article [3].

4.8.3 When a design rule is machine or factory dependent, the relevant parameters shall be documented.

4.8.4 When the properties of a similar material are used in lieu of the ones of the assessed material, not deemed sufficiently documented yet, a safety margin shall be considered.

4.9 Range of applicability

4.9.1 Such a range shall be proposed by the Manufacturer in accordance with API 17J and validated by the Society, as a result of the qualification activities carried out and in relation with the intended market needs as well as the limitations found.

The range of applicability shall be defined by considering different parameters, as relevant:

- pipe internal diameter
- internal and external min / max temperature range
- internal and external extreme pressure range:
  - maximum design pressure
  - maximum factory acceptance test pressure
  - maximum pressurization / depressurisation rates
- application system (static, dynamic)
- bore fluid (gas, oil, water, phase), and chemical composition (pH, CO_2, H_2S)
- raw material supplier, raw material characteristics
- appropriate parameters and parameter combinations (e.g. Internal Diameter x Design Pressure)
- annulus environment: fluid type chemical compatibility and corrosivity limitations
- inter-layer contact pressure
- geometrical parameters:
  - wire section geometry
  - wire strain = Wire thickness / Wire diameter
  - polymer thickness
  - polymer tape section geometry
  - for polymeric pressure sheath, size of the pressure vault wire gaps
- end-fitting possible adaptation limitations
- applicable Quality Assurance system: working instructions, acceptance criteria, control instructions
- manufacturing proven capabilities: machines and plant
- extent of testing.

4.10 Assessment report

4.10.1 In conclusion of the verification work, issuance of issues a detailed report on its independent assessment activities, mentioning all evidence gathered, allowing to establish the certificate granting the incorporation of the material into the Type Approval Certificate is made.

Limitations or restrictions due to missing evidence or partially unsatisfactory results, if any, are to be duly identified and informed for the knowledge and benefit of the End-User.

Before the formal incorporation of a new material into the Type Approval Certificate, intermediate certificates or attestations / statements may be proposed by the Society to the flexible pipe Manufacturer, see details in [8.1].

5 Manufacturing methods

5.1 General

5.1.1 Each phase of the manufacturing of the pipe and the end-fitting assembly is equally important. In order to ensure good continuity for all processes, for one product as well as from one product to another, the Manufacturer shall establish procedures describing all steps, detailing all necessary parameters to give machine operators sufficient guidance and provide clear instruction regarding tolerance control, or steps to be taken when abnormalities are observed.

5.1.2 As a minimum, the requirements set forth by API 17J section 7 as well as procedures listed in Tab 3 shall be documented for review.

5.1.3 Such procedures should also be allowed to be improved regularly through controlled revisions, in order to match operator needs or to incorporate technical changes, modifications of tolerances, etc. These modifications shall be subject to a regular review by the Society as required by API 17J.

5.1.4 The evaluation of the stability of the manufacturing processes shall be documented.

5.1.5 On top of the documentary review of the manufacturing documentation, periodic audits shall be performed in order to verify the correct implementation of the procedures in-situ. Considering the very high number of procedures and work instructions at stake for the fabrication of a flexible pipe line, Society experience is used to perform a risk analysis in order to identify the critical steps that requires a specific attention.

5.1.6 Regarding repair activities, the Manufacturer shall document by dedicated tests and/or calculations that the applicable repair procedures do not compromise the structural or long-term properties of the flexible pipe, nor its functional requirements.

5.1.7 For highly-specialized operations (e.g. end-fitting mounting, welding, non-destructive examination), the personnel qualification procedures will be reviewed by the Society.

5.1.8 When the manufacturing procedures have been completely verified to cover the fabrication of a whole line, the manufacturing site is incorporated within the Type Approval certification.

5.1.9 The verification activities are carried out based on the covered range of products and subsequent processes. In case some processes are subcontracted (e.g. machining of steel forgings, non-destructive technologies requiring specific skills etc.), they are considered with the same level of verification requirements.

5.2 Qualification of new machines, production lines or fabrication sites

5.2.1 In case a new machine is used, a new production line is set or even a complete new fabrication site is built, a specific assessment is conducted by the Society in order to certify that the performances of the final products are maintained.

5.2.2 The Manufacturer shall demonstrate that the existing procedures are adequate for consideration with the new items, possibly after adaptation to fit new constraints. To this end, it shall be demonstrated that API 17J fabrication requirements as well as [5.1] requirements are met.

5.2.3 If a new production site entail the use of new raw material suppliers, the Manufacturer shall demonstrate that the final performance of the product is unaltered. Requirements listed in Article [4] are applicable.

5.2.4 The Society will perform a risk analysis in order to identify potential gaps introduced by a new manufacturing machine, line or factory. The Q-FMECA procedure given in App 1 can be used for that purpose, with a specific focus on:

- key machine elements and tools
- key setting parameters of the machines
- key control and repair parameters
- local know-how and human aspects.

5.2.5 Depending on the outcome of the risk analysis, the Society may:

- Conduct specific on-site audits and inspections in order to confirm the good implementation of the manufacturing procedures in a new environment.
- Request the performance of specific full scale tests in order to confirm that the new machine, production line or factory is suitable for incorporation into the existing Type Approval. In case the tests are to be carried out in a different laboratory from the reference one already covered by the Type-Approval Certification, the test protocols shall be identical to the reference laboratory, or proven as being equivalent.

5.2.6 The capacity of a machine or factory may evolve with time. If such case, the qualification of the updated manufacturing range is subject to the requirements set in the present Article.

5.3 Manufacturing capability

5.3.1 Such a range shall be proposed by the Manufacturer and validated by the Society in relation with the fabrication site capabilities, possibly different in case of multiple fabrication sites.

The range of applicability shall be defined by considering different parameters, as relevant:

- product type
- product family as per API 17B (Family I: Smooth-bore pipes, Family II: 55° Rough-bore pipes, Family III: Reinforced rough-bore pipes)
- internal and outer diameters
- flexible pipe wall construction: Pressure armour arrangement, number of pairs of tensile armour
- qualified machines (profiling, sheathing, spiralling, armouring)
- design pressure
- design temperature
- application
- cumulative number of kilometres of pipe manufactured.

5.4 Assessment report

5.4.1 In conclusion of the verification work, the Society will issue a detailed report on its independent assessment activities, mentioning all evidence gathered, allowing to establish the certificate describing the covered processes, procedures and production sites within the Type Approval is made.

Limitations or restrictions due to missing evidence or partially unsatisfactory results, if any, are to be duly identified and informed for the knowledge and benefit of the End-User.

Before the formal incorporation of a new solution into the Type Approval Certificate, intermediate certificates or attestations / statements may be proposed by the Society to the flexible pipe Manufacturer.

6 Design rules

6.1 General

6.1.1 The design rules are defined by a document or a set of documents that shall be produced by the Manufacturer in order to consign its overall pipe design procedure. Such design rules allow gathering the three main aspects of the design described above (individual design methodologies, materials qualification and fabrication rules), making the link between them and also capitalizing on the Manufacturer's know-how. Therefore, they are a key element to be integrated within the Type Approval process as they give consistency to the various ranges established individually.

6.1.2 The design rules shall include, as a minimum:

- A description of the Manufacturer's design principle, available layer types and available components by layer, e.g. armour geometries, armour material grades, polymer materials.
- A list of material data to be considered for design. This data is based on material qualification tests and/or Manufacturer's requirements and should provide safe values to be used for design.
- A material selection rule, based on material qualification, indicating which materials are to be used for each layer given the properties of the transported fluid as well as the operating conditions (pressure, temperature). Through the definition of domains of use, the material selection rules are essential to prevent the occurrence of some failure modes or mechanisms (corrosion resistance, Hydrogen-Induced Cracking (HIC) / Sulfide Stress Cracking (SSC) test, blistering, …) without dedicated prediction models. In parallel, a design methodology should be developed to estimate conservative annulus environment - chemical composition, pH, temperature - for the selection of metallic and non-metallic materials in the annulus considering diffusion of chemical species from the bore through the polymeric sheathes and presence of components in the annulus. Regarding steel wire grades selection with respect to the sour conditions, methodologies based on the H_2S consumption phenomenon need to be thoroughly validated.
- A general design procedure for pipe cross-section, addressing the following points: pipe layout rules (e.g. order of layers, relative laying directions, optional layers), preferred design solutions, preferred components combinations (e.g. carcass / inner pressure sheath/pressure armours association), forbidden designs (e.g. limitation on the maximum number of components or layers, pressure armours with large gaps on polymer prone to creeping), pre-design methodology in order to outline a structure before performing refined analyses (e.g. estimation of polymer sheathes thicknesses and materials as well as type and number of reinforcing steel wires), list of failures modes to be studied (or omitted if relevant) together with the tools to be used, design flowchart mentioning the order in which the various refined analyses should be done but also the potential iterations on the design process, load cases and load conditions to be studied.
- A dedicated design rule for sealing of polymeric pressure sheath within the end-fitting, gathering seal design, seal materials, end-fitting mounting procedure, manufacturing tolerances, control method to ensure suitable seal activation for the different polymer sheath material and thickness, design pressure, minimum and maximum design temperature, and cyclic conditions.
- A dedicated design rule for pipes intended for dynamic applications. In particular, the list of applicable S-N curves shall be documented and the procedure of S-N curve selection as a function of the annulus environment shall be established.
- A dedicated methodology for the determination of the CO_2 fugacity in the pipe annulus, as not standardized in API 17J at the time of issuance of the present Guidance Note.
- A status regarding the qualification range of design methodologies, materials and manufacturability.
- A guideline for the use of the individual pipe design tools or methodologies, indicating their potential interactions.
- Any rule specifically linked to a classification of the pipe: static or dynamic category, pipe function (production, injection, export), type (flowline, riser, jumper), family as per API 17B (I, II or III), fluid characteristics and content (liquid or gas, presence of water, hydrocarbons, chemicals, acids,…).
- The manufacturability limitations either due to the capacities of the machines (e.g. maximum number of wires of an armouring machine, maximum length of lines due to reel limits), the applicability of a design methodology (e.g. limited to a given machine or factory), or to the need for qualification (e.g. laying of thick component on small diameter, extrusion of a thick polymer layer). These limitations should be in accordance with the fabrication procedures and capability ranges.
- Any specific post-manufacturing conditions linked to a given design: For instance FAT over-pressurization to relieve residual stresses, annulus free-flooding design to limit contact pressures or any operating conditions to be met (wet storage duration, depressurization rates, …).
- Any particular fabrication aspect needed to be met for a specific design (e.g. specific criteria for defects acceptance for static and dynamic pipes or specific fabrication tolerances).
- A procedure associated to the design of end-fittings (definition of components, sizing of components, choice of materials, mounting requirements) and of the end-fitting sealing system.
- Any other prescription needed to meet the requirements of API 17J.

6.1.3 Regarding the resistance of flexible pipes wires against CO_2-induced Stress Corrosion Cracking (SCC), no guidance is available in API 17J at the time of issuance of the present Note. The Manufacturer is expected to provide a testing-based design rule regarding flexible pipe design against SCC.

6.1.4 The design rules may also include other elements relevant only for the Manufacturer such as cost aspects (e.g. optimisation of the design based on overall cost), time aspects (e.g. consideration of procurement and fabrication durations in the design process) or any specific prescription needed to be in conformity with a standard or specification other than API 17J. Such elements would be disregarded and not covered by the Type Approval certification.

7 Quality

7.1 Quality Assurance / Quality Control procedures

7.1.1 Quality Assurance and Quality Control are important considerations in the production of flexible steel pipes, the latter being complex structures with significant inspection and testing of details throughout the fabrication of the pipe and end-fittings. The Manufacturer shall therefore implement a QA system complying with a recognized standard such as ISO 9001 for assessment by the Society.

7.1.2 As part of this system, the Manufacturer shall endeavour or make all necessary efforts to:

- obtain and maintain products of good quality in order to permanently satisfy the Purchasers and End-users' demand
- make sure internally that the required quality is reached and maintained
- ensure the Purchasers and End-users that the required quality is reached and maintained
- ensure that the Society is provided with all the necessary information required to achieve its verification work.

7.1.3 In order to be efficient, the QA system shall be well adapted to the company activity and its objectives are to be clearly explained to all employees who are involved in the quality procedures and controls.

7.1.4 The QA system shall be clearly organized with procedures and means to implement them, and cover all main phases of manufacture, listed below:

- design
- raw materials procurement
- fabrication
- control
- assessment of non-conformities
- corrective actions
- documentation.

7.1.5 For any new material, product, testing activities or manufacturing trials, the Manufacturer shall prepare a Quality Plan in good agreement with the management system of the quality, for review. The Quality Plan shall define:

- the objectives of quality to be reached
- the distribution of the responsibilities during the different steps of the projects
- the specification and procedures to be implemented
- the appropriate tests / inspection programmes to be carried out
- the procedures which allow modifications to this plan during the project
- any other point which is necessary to reach the objective.

7.1.6 All the procedures and the system will be investigated and assessed by in the frame of the Type Approval certification to provide sufficient guarantees for a high quality level for flexible pipe products.

7.2 Operating experience feedback

7.2.1 The topic of the verification scheme for flexible pipes presented in this note on a conceptual level relies on two distinct phases: a generic phase Type Approval Certificate (TAC) and a project phase (IRC/COC). In order to close the loop and improve the overall efficiency of the verification, an important step is to capitalize on the operating experience of the industry based on the achievement of actual projects (refer to Sec 1, Fig 5). This can be done at various levels, as described below.

7.2.2 The track record of a manufacturer based on the delivery, installation and operation of flexible pipes can be favourably used in the Type Approval integration process of a new pipe concept, methodology, component or material. A consistent, auditable track record shall be made available to the Society and include as a minimum the following data:

- client and project names
- type of line: Gas injection, gas production, oil production, water injection, etc.
- sweet / sour service application
- application: Static or dynamic
- pipe characteristics: Internal diameter, length
- layer characteristics
  - thickness of the polymer sheath and polymer layer type e.g. tube, pressure sheath, outer sheath
  - wire / strip type, size and grade.
- water depth
- range of pressures
- range of temperatures
- time spent in service, if available.

7.2.3 During a project certification (IRC/COC) supported by the Type Approval documentation:

- the lessons learnt from the review of the actual use of the type-approved methodologies can be used to continuously improve the Type Approval certification.
- any technology-related work that may have been triggered by project-specific needs can be consolidated into the Type Approval documentation.

7.2.4 All the relevant elements of field experience put forward by the industry through publications, technical documents (e.g. Handbook on Design and operation of flexible pipes), or JIPs (e.g. Sureflex JIP Report) are considered for Type Approval certification.

7.2.5 In case of unsatisfactory experience during manufacturing, factory acceptance testing or in operation known by the Manufacturer such as pipe failure or major unexpected damage, the Manufacturer shall inform the Society. The Manufacturer shall further perform a root cause analysis in order to identify the origins of the event and present it to the Society for assessment. The potential impact of this event on the Type Approval is subject to the identified cause (e.g. inaccurate design methodology, manufacturing non-conformity, material defect, design error, unexpected failure mode) and may lead to Type Approval range limitations until resolution of the identified issue.

8 Execution

8.1 Deliverables

8.1.1 The main deliverables generated upon satisfactory assessment are the Type Approval Certificate (TAC) as well as associated individual technical certificates and reports, these ones forming together the design methodology verification report as per API17J terminology.

8.1.2 The Type Approval Certificate is a synoptic document describing all the main results of the Type Approval assessment work. In particular, the following elements are presented:

- The certificate issuance and expiration dates.
- The overall manufacturing capability of the Manufacturer, for each manufacturing unit, with:
  - the manufacturing unit location
  - the pipe family as per API17B
  - the range of pipe internal diameter
  - the range of pipe maximum design pressures
  - the range of pipe maximum and minimum design temperatures
  - the pipe application: static, dynamic, sweet and sour service
  - the manufacturing track record (Total manufactured length of pipe).

- The design methodologies and tools:
  - the failure modes covered
  - the certified tools with their version number as well as the related failure mode(s)
  - the design criterion covered by each tool for the related failure mode
  - the range of use of each tool for each design parameter
  - the limitations of each tool, if any
  - the Society additional key remarks, if any
  - the reference to the associated detailed deliverables.
- Materials:
  - the materials certified per layer
  - the materials application / domain of use
  - the Society additional key remarks, if any
  - the reference to the associated detailed deliverables.
- The certified design and manufacturing procedures for each manufacturing unit, as well as the reference to the associated detailed deliverables.

  The certified manufacturing units and machines, including specific manufacturing limitations, if any.
- The experimental full-scale testing results for key failure modes:
  - hydrostatic straight collapse test results for various pipe internal diameter and pipe family
  - hydrostatic curved collapse test results for various pipe internal diameter and pipe family
  - burst test results for various pipe internal diameter and pipe family
  - fatigue test results for various pipe internal diameter and pressure armour type
  - bend stiffener fatigue test results for various pipe internal diameter, if any
  - lateral buckling tests results for various pipe internal diameter and curvature range.
- The summarized track record of supplied products as described in [7.2.2].
- Any outstanding remark emphasized by the Society, regarding executed or on-going work.

8.1.3 For practical reasons, dedicated certificates and reports are issued to cover specific design methods, design rules, material or manufacturing methods.

- these reports provide additional details on the verification process, test results, assumptions, ranges covered, ranges building procedure, possible conditions of use or limitations, activities remaining to be completed (refer to [3.6], [4.10] and [5.4])
- these documents are referenced in the Type Approval Certificate (see Fig 4) and shall be made available by the Manufacturer for consultation on Purchaser request.

Figure 4 : Type Approval deliverables

8.1.4 Considering the time span for incorporation within the Type Approval Certificate, interim certificates or statements possibly associated to specific reports can be issued in order to document the progress of assessment activities (e.g. related to new technology qualification).

8.2 Validity and maintenance

8.2.1 In order to keep up-to-date with the day-to-day practice in applying the approved procedures, the validity of the Type Approval Certificate granted to a Manufacturer is subordinated to:

- A Type Approval maintenance, which consists in a system of regular audits, supplemented by the incorporation of the updated design rules, procedures or materials. This work is typically carried out on a yearly basis.
- A Type Approval renewal, which consists in a thorough audit and is aimed at reconfirming the Type Approval Certificate in force. This work that allows incorporating major updates (e.g. incorporation of a new manufacturing unit, consideration of a new revisions of API 17J) is typically carried out every 3 years.

The Manufacturer shall keep the Society informed of any changes in the design, choice of parts or materials and changes in the system of production and inspection. Such changes, unsatisfactory experience or amendments of applied rules, regulations, Codes, Standards or approval practice by the Society, may at any time lead to the withdrawal of the Certificate of Type Approval.

8.3 Extension of certified ranges

8.3.1 In case any extension of a validated range within the Type Approval (design methodology, material, manufacturing) is required, a risk analysis shall be carried out in order to identify the associated risks and mitigate them through analyses and/or adequate testing. The Q-FMECA process developed in App 1 for the qualification of new technologies can be considered for this purpose.

When extending a range of use covered by the Type Approval certification, on top of specific qualification requirements put forward by the risk analysis described above, the same requirements as the ones described for the initial Type Approval apply to the extension, namely:

- Article [3] for extension of range of design methodologies
- Article [4] for extension of range of use of materials
- Article [5] for extension of manufacturing capabilities.

9 Ancillary items

9.1 General

9.1.1 The design methodologies, materials and manufacturing of API 17L1/L2 ancillary equipment used in flexible pipe systems such as bend stiffeners, bend restrictors or buoyancy modules, are not specifically covered in this Section.

In case the flexible pipe Manufacturer also addresses the design and / or production of an ancillary equipment, it can be included within The Type Approval Certificate. In this situation, the assessment principles set forth in the present Section are to be used, in complement with API 17L1/L2 specific requirements.

SECTION 3 PROJECT CERTIFICATION

1 General

1.1

1.1.1 In contrast to the generic technology related assessment work described in Sec 2, the project certification refers to the certification of a specific line for a specific application, when a Purchaser has established specifications to define operating requirements and issued an order to a Manufacturer.

1.1.2 As the flexible line design and manufacturing are not necessarily carried out nor verified by the same units and according to the same schedules, it is convenient to split the project certification into three parts:

- an initial gap analysis aimed at identifying at an early stage non-qualified or non-Type-Approved items.
- a certification of the design aspects, called Independent Review Certificate (IRC).
- a certification of the manufacturing aspects, called Certificate Of Conformity (COC).

1.1.3 The project certification shall be based upon the upstream verification work consigned within the Type Approval Certificate. The overall workflow is illustrated in Sec 1, Fig 3.

1.1.4 The specific case of project certification without a supporting Type Approval Certificate is not covered by the present note, since API 17J requires that the Manufacturer provide a Design Methodology Verification Report produced by an IVA. However, should such case arises, a specific assessment would be undertaken by the Society to document the suitability of the proposed design for the project conditions (refer to following Article [2] Gap Analysis).

1.1.5 In case the supporting Type Approval Certificate is not issued by the Society but by another IVA, the Type Approval Certificate as well as the Design Methodology Verification Report / Type Approval Report shall be provided to the Society. It is expected that the same level of information as the one given in the Type Approval Certificate (refer to Sec 2, [8.1]) will be presented in this Type Approval Certificate.

1.1.6 In this Section, the most comprehensive verification activities as recommended by the Society are described. Depending on its own needs, the Purchaser may request a partial scope of verification.

2 Gap analysis

2.1

2.1.1 As a first step of the verification, the Society will verify that for the scrutinized flexible pipe lines, the functional and design requirements from API 17J as well as additional Purchaser's specifications are covered by the Type Approved ranges.

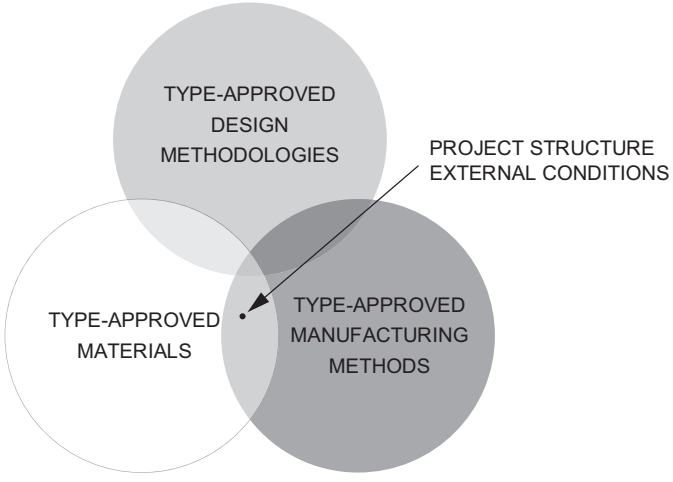
2.1.2 The qualification status of each relevant design methodology, fabrication capability or material is scrutinized independently in this process (See Fig 1, which exemplifies the case of unqualified design methodologies).

2.1.3 API 17J / API 17B testing requirements are examined with the objective of determining:

- the tests that do not need to be executed due to sufficient experimental evidences within the Type Approval
- the tests that shall be executed.

2.1.4 If non-qualified aspects emerge from this gap analysis, a Q-FMECA exercise as per App 1 shall be performed with the objectives of determining if a mitigation plan is required or if the proposed design can be accepted as is based on limited utilization within the project conditions. Mitigation actions can include further project qualification work (e.g. additional studies, prototype testing), design assumptions refinement or design modification.

Figure 1 : Qualification envelopes



2.1.5 In case a qualification programme is defined:

- Its review procedure will be as specified in App 1
- The outcome of the qualification activities will be considered for consolidation and incorporation within the Type Approval upon its next renewal.

2.1.6 As this review step can impact the overall project schedule and costs due to supplementary qualification requirements, it is recommended to involve the Society as early as possible, at best during tender phase.

3 Independent review certificate

3.1

3.1.1 The Independent Review Certificate (IRC) establishes the conformity between the flexible pipe design and the API 17J requirements as well as the Purchaser's technical specifications.

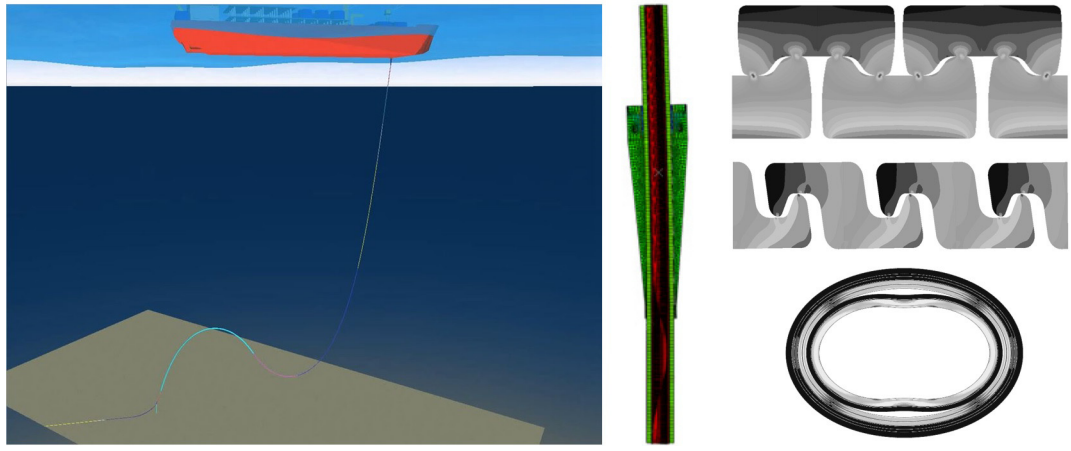
3.1.2 To this end, the Manufacturer shall produce a Design Report for assessment.

3.1.3 The flexible pipe system design premise including all project assumptions (design values, transported fluid characteristics, operating data, floating vessel characteristics, meteocean conditions) shall be provided together with project specifications.

3.1.4 As part of the verification process, the Society will:

- Validate the correct implementation of the type-approved procedures, methodologies and tools.
- Validate the material selection.
- Review any methodology and/or analysis which is not encapsulated within the Type Approval (e.g. specific FE analyses, system-related issues or global analyses such as dynamic analyses, upheaval buckling analyses, clashing analyses, …).
- Check that the API 17J requirements and design criteria are met in the flexible pipe body as well as in the end-fitting.
- Regarding the end-fitting design, in addition to its mechanical strength and termination of the different flexible pipe layer (including tensile armour anchoring), detailed end-fitting drawings are to be examined. Correct implementation of the polymer sheath sealing system design rule is to be checked.
- Check that all the requirements particular to the Purchaser's specifications (i.e. supplementary requirements to API 17J) are met as these ones are by essence not guaranteed by the API 17J Type Approval Certificate.
- Assess the suitability of the proposed design to the End-user intended application as well as to the temporary phases such as installation.
- If relevant, for any design methodology or material that would not be incorporated within the Type Approval, review the existing validation or qualification dossier, with a particular focus on the project case.
- If relevant, follow and review any qualification activity required by the Purchaser or to bridge the gap with already qualified products (see review procedure in Article [2]).
- Perform selective independent analyses to verify critical aspects of the design and confirm some calculations results (see Fig 2). Typically, global dynamic analysis are carried out.

Figure 2 : Independent Calculations



3.1.5 While the Type Approval Certificate is mainly focused on the flexible pipe product, the project certification shall ensure that the whole flexible pipe system (including ancillary items) meets the regulatory and Purchaser requirements. The Society will therefore review the design, manufacturing and testing activities related to the ancillary items. In case ancillary items rely on Type-Approved methodologies, the flexible pipe Manufacturer shall provide the Type Approval documentation from its sub-supplier for verification.

3.1.6 From a practical point a view, the review work consists both in desktop documentary review (design documentation) as well as physical attendance to testing activities. The communication and resolution of outstanding comments is organized through the issuance of notes of comments and participation to technical meetings between all involved parties.

3.1.7 After the verification process, the Society will issue an Independent Review Certificate (IRC) and a technical report describing the review work carried out and establishing that the design is in accordance with API 17J requirements and Purchaser specifications.

3.1.8 Should an outstanding remark emerge from the verification work, it would be highlighted in the Independent Review Certificate (IRC).

3.1.9 In case of pending items (test results, analyses), an Interim IRC may be issued until the missing activities are finalized.

4 Certificate of conformity

4.1

4.1.1 The Independent Review Certificate (IRC) described in Article [3] is a design-related document. The Certificate Of Conformity (COC) however establishes the final conformity (design + manufacturing) between the flexible pipe and the API 17J requirements as well as the Purchaser's technical specifications.

4.1.2 To this end, the Manufacturer shall issue a Manufacturing Quality Plan for assessment by the Society.

4.1.3 As part of the verification process required for issuance of the Certificate Of Conformity (COC) for each project flexible line, the Society will:

- Verify the material traceability and the welders' qualification.
- Survey the fabrication of the pipe as well as its assembly with the end-fittings.
- Confirm that the pipe has been manufactured in accordance with the Type-Approved fabrication procedures, work instructions and control procedures as well as with the specific Purchaser's requirements, if any.
- Review the assessment of potential non-conformities together with the associated corrective actions. To this end, the Manufacturer shall document by dedicated tests and/or calculations that the repairs to the flexible pipe do not compromise the structural or long-term properties of the pipe
- If relevant, review any manufacturing aspect that would not be covered by the Type Approval (e.g. project-specific acceptance criteria for defects or tolerances, new procedure, new machine).
- Witness any required production tests and certify the obtained results.

- Witness and certify that the Factory Acceptance Test (FAT) has been carried out in accordance with API 17J requirements.
- Ensure that the design of the line has been granted an Independent Review Certificate.

4.1.4 From a practical point a view, the verification work consists both in desktop documentary review (manufacturing documentation) as well as physical attendance to the line manufacturing and contractual testing. During this process, the Society will issue notes of comments as well as inspection reports as working documents.

4.1.5 The communication and resolution of outstanding comments is organized through the issuance of notes of comments and participation to technical meetings between all involved parties.

SECTION 4 OPERATIONAL MANAGEMENT

1 General

1.1 Scope

1.1.1 Operational management relates to the way the flexible pipe system is operated throughout its lifetime, including data collection, monitoring, inspections, damage assessment as well as potential lifetime extension.

The Owner of the flexible pipe system may request from the Society a Third-Party review in order to state that its flexible pipe system meets a sufficient safety level, defined by the Owner or by an external regulator. Examples of Third-Party work carried out during the operation of a flexible pipe include the validation of the implementation of an integrity management system, the evaluation of the fitness for service of the system following an operational incident or the lifetime extension of line.

For any operational-related assessment work, the Society will issue a Certificate and technical report describing the verification activities carried out as well as the conclusions and recommendations, if any. In case the scope of the review is more limited than the review requirements put forward in [3.2] and [4.2], a Statement will be issued in lieu of a Certificate.

2 Integrity management system

2.1 General

2.1.1 The integrity management system is a quality process set up by the Owner in order to establish the historicity of the operated flexible pipe system, covering the data collection and storage of various aspects such as: Original design and manufacturing documentation, installation data, operational data, bore fluid data, environmental data, inspection results, monitoring, incidents, damage assessments, repairs, retrieval and dissection of other lines in the field, mitigation actions.

While the set-up of an integrity management system is not sufficient to establish the flexible pipe system fitness for service or lifetime extension, it is considered to be a strong prerequisite to be submitted to the Society for any assessment work, in order to confirm that the operational data is robust and comprehensive.

2.2 Documentation

2.2.1 The End-user is responsible for safe operation of the flexible pipeline system. With this objective, an integrity management system shall be devised and followed by the End-user.

As part of the integrity management system, execution of the monitoring and inspection plan shall be documented carefully including:

- Recording of incidents.
- History of transported fluid characteristics, including analysis of out of specification fluid events (e.g. above maximum operating temperature, excess of contaminants).
- Regular subsea inspection surveys videos and reports of flexible pipe system aiming at detecting situations potentially impacting the flexible pipe system integrity (e.g. outer sheath breach, marine growth above design premise assumptions, unforeseen upheaval buckling, condition of ancillary items, riser global configuration geometry).
- Annulus condition assessments shall be regularly performed including, if relevant, analysis reports of gas vented at end-fitting (flowrate, composition, frequency of vent valves openings).
- Learnings from corrosion of metallic components and ageing of polymeric sheath management (e.g. corrosion / ageing coupons). If relevant, records of follow up of the corrosion inhibitor injection strategy.
- Evidence of maintenance of the cathodic protection system.
- If relevant, actual meteocean conditions experienced during operation, and actual floating vessel motions, allowing to document a possible margin (or gap) versus the assumptions of the extreme and fatigue global dynamic analyses.

Above information are key essential data for subsequent condition assessment, fitness for service assessment and lifetime extension studies.

3 Fitness for service

3.1 General

3.1.1 The fitness for service is the process by which the integrity of the flexible pipe system is documented to be maintained, after an incident or damage to the system occurred. After such major event during service, the Society may be called upon by the Owner to state the flexible pipe systems remains fit for its intended service.

Contrary to the lifetime extension process described in Article [4], the fitness for service assessment is carried out to confirm the integrity of the system during its initial design life.

In order to ensure the integrity of the flexible pipe system, a systematic FMECA shall be carried out in order to identify the main threats due to the combined actions of the operational data and the incident or damage recorded. App 1 presents a general framework for FMECA. Contrary to the Q-FMECA that can be carried out during design phases:

- The present analysis shall be able to also address other specific threats such as:
  - Threats due to the known installation or operational events.
  - Threats due to the discrepancies between the original design requirements and the up-to-date design requirements from latest applicable standards (which may be more stringent or introduce design against additional failure modes)
  - Threats evidenced by shared operating experience, e.g. SureFlex JIP (see Sec 1, [5.1.4]).
  - Threats due to the main incident or damage that triggered the fitness for service evaluation.
- On top of (re)-qualification activities, risk reduction may be obtained by operational mitigation actions (e.g. increased inspection frequency, reduced operational pressure).

As part of the fitness for service process of a flexible pipe, it is highly recommended that the Manufacturer of the line is involved, in particular during the FMECA session (knowledge of its product and of historical design practices) or if additional analyses pertaining to the pipe local behaviour shall be carried out (proprietary design methodologies and design data). Similarly, the process will benefit from the existence of a Type Approval Certificate (see Sec 2) by the Society related to the investigated product.

3.2 Assessment

3.2.1 The assessment of the fitness for service dossier will include:

- The collection of the whole documentation related to the original design and manufacturing as well as to operational events.
- The review of the gaps between the original design requirements and to the state-of-the-art requirements for flexible pipes.
- The review of the gaps between the original design assumptions and to recorded operational data.
- The review of the integrity management system data (see Article [2]) with the objective of estimating the current integrity level of the line.
- The review of / participation to the FMECA (see [3.1]) and approval of the identified threats and mitigation actions.
- The review of the root cause analysis of the major event / damage that triggered the fitness for service process.
- The assessment of the risk mitigations actions (e.g. engineering analyses review, approval of inspection plan, follow-up of coupon laboratory analyses, qualification tests).

4 Lifetime extension

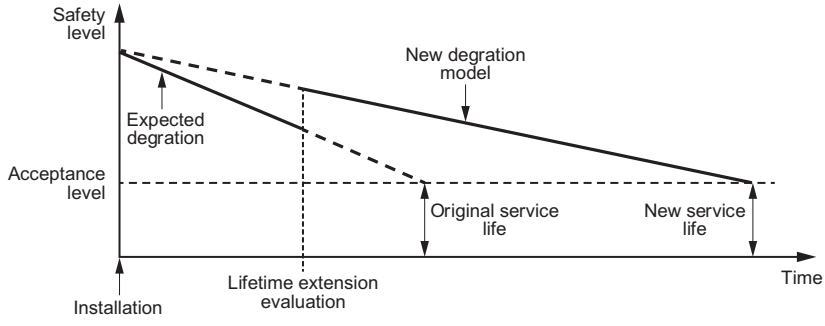
4.1 General

4.1.1 The lifetime extension is the process by which the flexible pipe system is documented to be requalified for a safe operation for a service life higher than the one anticipated in the initial design phase. To that end, any threat to the pipe system - either due to the extended lifetime or to the recorded operational events - shall be assessed and documented.

As the lifetime extension intrinsically entail an increased operational duration, a particular focus shall be paid to the time-evolving degradation mechanisms such as corrosion, fatigue, erosion, wear, ageing, alteration of functional properties of ancillary items (e.g. loss of buoyancy). The lifetime extension process shall aim at better estimating the degradation kinetics using operational data and/or refined modelling. A typical representation of the degradation process as considered by NORSOK Y-002 or IOGP-623 is illustrated in Fig 1.

The Society will perform the Lifetime Extension assessment for lifetime extension process following recognized standards such as NORSOK Y-002, complemented by IOGP-623 regarding flexible pipe specific features.

Figure 1 : Evaluation of integrity level through time (IOGP-623)



The flexible pipe systems being complex by essence, the way to ensure the integrity can differ depending on the design of the investigated system. Therefore, a systematic FMECA shall be carried out in order to identify the main threat to the system. App 1 presents a general framework for FMECA. Contrary to the Q-FMECA that can be carried out during design phases:

- The present analysis shall be able to also address specific threats related to the condition assessment such as:
  - Threats due to the known installation or operational events.
  - Threats due to the discrepancies between the original design requirements and the up-to-date design requirements from latest applicable standards (which may be more stringent or introduce design against additional failure modes)
  - Threats evidenced by shared operating experience, e.g. Sureflex JIP (see Sec 1, [5.1.4]).
  - Threats due to the lesser knowledge of flexible pipes operated for extended lives.
- On top of (re)-qualification activities, risk reduction may be obtained by operational mitigation actions (e.g. increased inspection frequency, reduced operational pressure).

As part of the lifetime extension assessment process of a flexible pipe, it is highly recommended that the Manufacturer of the line is involved, in particular during the FMECA session (knowledge of its product and of historical design practices) or if additional analyses pertaining to the pipe local behaviour shall be carried out (proprietary design methodologies and design data). Similarly, the lifetime extension assessment process will benefit from the existence of a Type Approval Certificate (see Sec 2) by the Society related to the investigated product.

4.2 Lifetime extension assessment

4.2.1 The assessment of the lifetime extension dossier will include:

- The collection of the whole documentation related to the original design and manufacturing as well as to operational events.
- The review of the lifetime extension design premises (e.g. service life extension duration, conditions).
- The review of the gaps between the original design requirements and to the state-of-the-art requirements for flexible pipes.
- The review of the gaps between the original design assumptions and to recorded operational data.
- The review of the integrity management system data (see Article [2]) with the objective of estimating the current integrity level of the line.
- The review of / participation to the FMECA (see [4.1]) and approval of the identified threats and mitigation actions.
- The assessment of the risk mitigations actions (e.g. engineering analyses review, approval of inspection plan, follow-up of coupon laboratory analyses, qualification tests).

APPENDIX 1 QUALIFICATION OF NEW TECHNOLOGY

1 Qualification Failure Mode Effects and Criticality Analysis (Q-FMECA)

1.1

1.1.1 When new technologies are developed, a common exercise to define the qualification programme aimed at demonstrating the suitability of the new technology is to carry out a Q-FMECA (Qualification Failure Mode Effects and Criticality Analysis (Q-FMECA)).

The Q-FMECA exercise shall be exhaustive, scrutinizing all possible failure modes versus all functions the new technology is expected to fulfil during all phases of its life related to the flexible pipe. It is therefore a prerequisite to carry out a detailed functional analysis, identifying all expected functions throughout procurement, fabrication of the pipe structure and mounting of the end-fittings at the flexible pipe manufacturing plant, offshore site installation (and recovery in service, similar to installation situation), and final use by Client (production of hydrocarbons, injection, …).

As part of the Q-FMECA process, it is essential to ensure that failure modes susceptible to be triggered by the introduction of the new technology have been ascertained. As a starting point, API 17B Table 30 and 31 as well as A.3.3 from Handbook on Design and operation of flexible pipes can be considered as a guideline listing possible failure modes.

The proposed format of the Q-FMECA is based upon existing FMECA types (API 17N, NI 525) with a focus on identifying required qualification activities for each identified failure mechanism. The Q-FMECA process investigates in a systematic way all functions fulfilled by the considered new technology in the flexible pipe, throughout all phases of its life, from procurement to end of life, to identify all corresponding failures, their modes, causes and consequences. The purpose shall be to identify qualifications required to prevent or mitigate all these possible failures, as much as reasonably practicable.

The list of full scale tests required to achieve qualification of the new technology shall be established, considering as a starting point the list given in Tab 1 defined from API 17B, complemented as required by aspects mentioned above, other design change situations when relevant, and based on Q-FMECA findings and relevant considerations to manage risks as low as reasonably practicable. In Tab 1, the right column identifies the full-scale test requirements depending on the layer impacted by the new technology. The need for other full-scale tests, not listed in Tab 1, may arise to sort out risks pointed out during the functional analysis and subsequent Q-FMECA. Examples of additional full-scale tests include:

- Diffusion test, to ascertain improved permeation properties).
- Combined internal pressure and temperature cycling to ascertain internal sheath suitability versus susceptibility to cracking.
- Full scale test to verify the feasibility of installation of the flexible pipe embodying the new internal pressure sheath material, considering installation bending loads and installation environment, and verify no cracking may occur during installation (effects on selection of internal pressure sheath).
- Full scale test to verify the holding capacity of the flexible pipe during installation, verify no sliding of flexible pipe, or of an internal layer in relation to another, leading to flexible pipe structural disorganization, during installation inside installation equipment.
- Full scale corrosion test, in order to verify the resistance of the armour wires versus severe environment exposure, e.g. high CO_2 content possibly leading to Stress Corrosion Cracking (SCC).

A typical organisation for the Q-FMECA table, to be built-up in order to lead to an exhaustive report, is given in Tab 2.

In absence of Manufacturer's own risk notation system, the notation system given in Tab 3 may be applied.

When all concerned parties agree to decide on required qualification based on consensus, the criticality quantification (S x F) or (S x F x D) may be omitted, the exercise is then named FMEA.

Table 1 : List of potential Full-Scale Tests required, subject to Q-FMECA conclusions

Class	Prototype test	Layer impacted by New Technology							
		Carcass	Pressure sheath / Inner liner	Pressure or tensile wire	Anti-wear tape	Antibuckling tape	Insulation	Intermediate, External and protection sheath	End Fitting
I / Standard	Burst		X	X					X
	Axial tension	X		X					X
	Collapse	X		X					
	Temperature (cycling)		X						X
II / Special	Dynamic fatigue		X	X	X	X			X
	Crush strength	X		X				X	
	Combined bending & tensile	X	X	X					
	Sour service		X	X					X
	Fire						X	X	X
	Erosion	X	X						
	Through flowline (pigging)	X	X						
	Combined pressure & tensile	X		X					X
	Outer sheath holding system							X	X
	External sealing system							X	X
	Dynamic tension - tension			X					X
	Curved collapse	X		X					
	Vent valve								X
III / Characterisation & other	Bending stiffness		X		X			X	
	Torsional stiffness			X		X			
	Abrasion							X	
	Rapid decompression	X	X						X
	Axial compression			X		X	X		
	Thermal characteristics / TEC		X				X	X	
	Arctic		X				X	X	X
	Weathering							X	
	Structural damping		X	X	X			X	
	Internal pressure cycling	X	X						X
	Lateral buckling (caisson / offshore)			X		X			
	Impact			X			X	X	X
IV / Other	Internal Pressure Sheath Dynamic		X						X
	Diffusion / Corrosion (CO_2 and / or H_2S) Test	X	X	X					
	Abrasion/Wear test							X	

Table 2 : Generic Q-FMECA Table

N°	Step **(1)**	Pipe art **(2)**	Possible failure mode **(3)**	Causes of failure **(4)**	Effects of the failure **(5)**	S. Severity ranking **(6)**	F. Frequency ranking **(6)**	D. Detection ranking **(6)**	S.F Risk category **(6)**	Risk criticality **(7)**	Mitigation through Qualification activity **(8)**

(1) Procurement, Design, Manufacturing, Installation, Production

(2) Material, Pipe structure, end-fitting

(3) Manner in which an items fails. Example: break of pressure vault

(4) Cause that leads to the failure of an item. Example: material defect leading to breakage

(5) Consequence of a failure mode in items of the operation, function or status of the item. Consequences of failure shall not be limited to the item but also to surrounding and interfacing systems, and HSE. Example: burst of pipe

(6) See Tab 3 for notation system

(7) S x F x D

(8) Mitigation required when: S x F x D is equal or greater than 20, or S x F equal to greater than 6

Table 3 : Generic Q-FMECA notation system

S. Severity of failure		F. Frequency of occurrence		D. Probability of detection	
1	Hardly Noticeable	1	Unlikely probability	1	Very high probability
2	Very small effects	2	Very small	2	High
3	Small effects	3	Small	3	Moderate
4	Moderate effects	4	Moderate	4	Small
5	High effects	5	High	5	Very small
6	Very high effects	6	Very high	6	Unlikely

2 Qualification programme documentation

2.1

2.1.1 Based on the outcome of the Q-FME(C)A carried out as per Article [1], the Manufacturer shall work out the required programme of qualification and prepare the corresponding documentation to organise the actions. The documentation to be established includes:

- the identification of the goals and nature of the solution
- the targeted range of use
- the Q-FME(C)A table establishing the risks and uncertainties that need to be addressed, supporting the Qualification Programme
- the qualification envelope, schedule of fabrication of test samples, with associated procedures (fabrication and control), Inspection and Test Plan ITP (or equivalent) showing the intended IVA involvement
- the list of qualification tests and associated procedures
- the list of engineering work / analyses to complement or justify the testing
- the qualification planning.

3 Society involvement

3.1

3.1.1 While the Technology Qualification phase can be carried out in a first stage before the outcome of the qualification campaign is submitted for Type Approval integration, it is recommended that the Society is involved in the Q-FMECA process in order to validate the qualification strategy during the early phase of development of the new technology and avoid the raising of outstanding issues after the finalization of the qualification campaign during the Type-Approval work.

As a general rule, the Q-FMECA session is a joint exercise during which both Manufacturer's and the Society experts are gathered with the objective of establishing the Q-FMECA table. Manufacturer and FMECA can be prepared in advance before being merged as part as the Q-FMECA session during which the final Q-FMECA is validated.

In case of involvement after the definition of the qualification plan, the Society will perform an internal Q-FMECA in order to validate the Manufacturer's Q-FMECA. In case a gap is identified, mitigation actions shall be discussed between the Society and Manufacturer (e.g. supplementary qualification activities, reduced range of use compared to initially targeted).

Assessment work consist in the following activities:

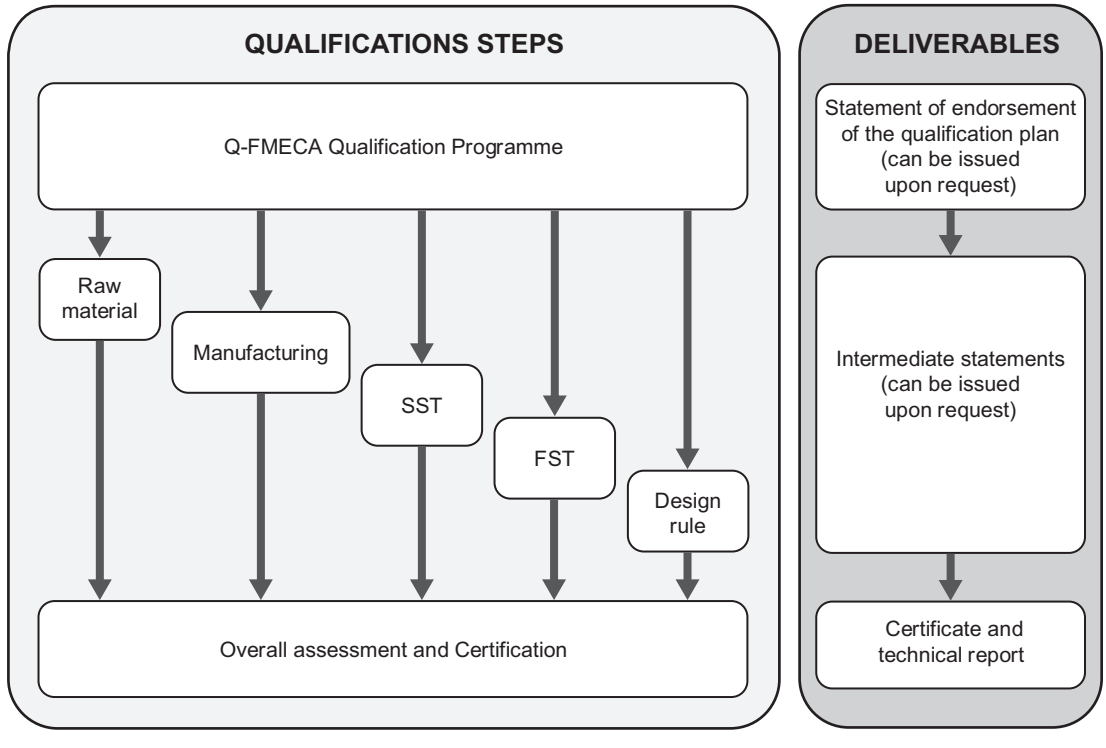
- The endorsement of the qualification programme, by the validation of the Q-FMECA as well as the agreement on the Society involvement during the qualification activities.
- The follow-up of the qualification activities, as defined by the qualification plan. For the review of the qualification activities, all the requirements established in Sec 2 are applicable, whenever relevant.

4 Deliverables

4.1 General

4.1.1 Various deliverables can be issued from the definition of the Q-FMECA until the execution of the qualification plan (see Fig 1).

Figure 1 : New technology qualification deliverables



Basic deliverables for the qualification of new technologies include:

- A statement of endorsement of the qualification programme
- A certificate and technical report summarizing the outcome of the qualification activities, establishing the conformity of the new technology to API 17J requirements as well as to potential additional requirements and presenting the range of use / application of the new technology.

In parallel, in order for the Manufacturer to demonstrate evidences of the progress of the qualification plan as well as its validation by an IVA, the Society can also issue intermediate statements before the completion of the qualification plan.

4.2 Relation with Type Approval Certification

4.2.1 As a general rule, the final certificate and technical report associated to the qualification of a new technology can be consolidated through the Type Approval documentation.

It is common that the qualification activities related to a new technology impact various items covered in the Type Approval. For instance, the development of a new pressure armour wire will potentially expand the design methodologies (e.g. burst, collapse, fatigue), the qualified materials or the manufacturing methods. In such cases, a specific work will be performed by the Society in order to reflect the outcome of the qualification activities into all the relevant existing Type Approval certificates.

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